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IGNEOUS INTRUSIONS AND ORE DEPOSITS OF THE ZONE OF FLOWAGE.

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INTRODUCTION.

IN an earlier[1] article presented under the above title it was considered that geological field evidence indicates a peculiar mechanism for igneous and ore intrusions within the so-called "Zone of Flowage," such that the igneous intrusions tend to be gneissic with their planes of foliation arranged parallel to the bedding, or gliding, planes of the intruded paragneisses; that their form is "saddle-like," phacolithic, lenticular, "sill-like," or *lit-par-lit;* and that the ore deposits formed during this stage of intrusion have the characteristics of igneous rocks formed under peculiar conditions.

[1] Andrews, E. C., "Igneous Intrusions and Ore Deposits," ECON. GEOL., vol. 21, pp. 81–89, 1926.

In the present note, the case of the Broken Hill igneous rocks and ore deposits is used as an illustration of the activities which appear to characterize the intrusion of igneous rocks in the "Zone of Flowage."

The note has been prepared as one of a series of "Studies for Students," seeing that the main facts of form considered in the accompanying description of Broken Hill in all probability may be matched in many other regions, forms so commonly known that they have become recognised as normal to certain large regions, and for that reason possibly their real significance may have escaped due attention in discussions dealing with the general principles of igneous intrusions. This psychological factor in scientific studies, as the late G. K. Gilbert informed me personally, is of the utmost importance. As an example of its operation the case of the erosive action of glaciers may be noted. It is well known that in regions such as the northern portions of Europe and North America, which had been overridden by great glaciers in recent geological time, there exist peculiar forms, similar and similarly situated, which have no exact counterparts in regions unaffected by recent extensive glaciation. These forms, until recent time, were accepted as "normal" to the landscape by those who had been born and bred among them. In other words they were explained as being due to the action of present-day activities, such as weathering and stream erosion. A simpler explanation of their origin, namely, as the result of erosion by recent glaciation, originated gradually in two ways, first, by investigations conducted in non-glaciated regions by geologists reared in areas of recent deglaciation, and secondly, by geologists who had been born and bred in non-glaciated areas. The one group, on entering the northern areas of America and Europe was amazed at beholding the wealth of forms all of which apparently were abnormal, the other was equally amazed at the absence from the new surroundings of the old familiar cirque, *roche-moutonnee,* drumlin, over-deepened valley, and faceted spur. Nevertheless even when the case had been set forth clearly in publications inspired by these "intellectual excursions" it took many years for "stay-at-home" geologists to regard the forms

under discussion as other than normal to the activities existing to-day in the same area.

To make the case under consideration clearer, namely, igneous intrusions in the so-called " Zone of Flowage," one field—Broken Hill—is selected for special consideration, the history of geological work conducted there being summarized, especially with regard to observations made during the period 1925–1929, a period during which a considerable amount of coördinated work has been carried out by the technical staffs of the various mines co-operating with the officers of the State Department of Mines.

Two lodes in particular are selected for special reference, namely, the Main Broken Hill Lode and its pocket-edition, the " Pinnacles Lode," ten miles distant. The general geology of the Broken Hill area proper is well known to mining geologists. Moreover, the igneous rocks and the ore deposits of the area have been exposed so well either by denudation or by the multitudinous mining excavations extant that the district is one out of which " demonstration might be expected naturally to arise."

A consideration of the significance of the occurrences follows the general description of them, and it is hoped that students may be induced to study other areas of marked former compression with a view to instituting careful comparisons with the Broken Hill area. In this connection it is, perhaps, scarcely necessary to impress upon students generally the necessity to distinguish carefully between igneous intrusions (and ore deposits) formed under the Broken Hill conditions cited, and those which have been formed possibly within the same area at a later period after the zone of flowage has become one of fracture, or tension, that is after the rocks intruded have passed by elevation and denudation from the regions of the abyssal chemical laboratories to those of shallow depth only.

From a study of Lindgren's [2] descriptions of ore deposits, it would seem that the Ducktown, Franklin Furnace (New Jersey), the Magnetite masses of Sweden, of the United States, and of Germany, the Homestake, Minas Geraes, The Rand, Kalgoorlie, and many other deposits, present problems in physical chemistry

[2] Lindgren, Waldemar, " Mineral Deposits," pp. 750–850, McGraw Hill, 1928.

very similar to those to be found at Broken Hill. Great geological age is not necessarily implied for rock exposures such as those described for Broken Hill. Generally, however, the opportunities for observation of outcrops of the rock types under consideration are considerably greater in the case of pre-Cambrian examples than they are in that of rocks formed during much later periods, owing to the increased possibilities for profound denudation in areas of long continued uplift.

Broken Hill Geology.

General Statement.

The Main Broken Hill Lode is of considerable size. It was prospected in 1884. Since that date material, to the amount of 42,000,000 (forty-two millions) long tons, has been won. The average rate of depletion is from 1,000,000 to 1,250,000 tons a year. The actual ore reserves, estimated on an extremely conservative basis, amount to 13,500,000 tons, while the "probable" reserves amount, at least, to 7,000,000 tons. This maintenance of a reserve of 13,000,000 tons has persisted almost uninterruptedly from 1906, since which time more than 26,000,000 tons of ore have been won. The ore is a sulphide of lead and zinc in a gangue of dense silicates, calcite, and quartz. Incidentally it may be noted that the gross value of the lead, zinc, silver, cadmium, copper, and gold recovered exceeds £160,000,000 ($800,000,000).

Mining geologists have not been attached to the permanent staffs of the Broken Hill Companies, with the result that very much information of value regarding the geological occurrence of the Broken Hill Lodes has been lost to the scientific world, owing to the necessity for close-filling of the mining stopes as soon as the ore has been extracted. The structural relations of the main Broken Hill Lode at all points with the country rock have never been explained satisfactorily owing to the failure to secure continuity and coördination of observations of mining faces as they have been exposed.

Since 1922, however, when the official report on the Broken

Hill field was published,[3] the underground workings have been inspected officially at periodic intervals, especially by E. J. Kenny.[4] It is proposed, as a result of these periodic examinations, conducted mainly since 1924, to furnish a simple statement of the method of lode occurrence in that area. The statement is presented in a manner such that the explanation may be expected to rise, as it were, out of the mere description of the facts of form observed. Special acknowledgments are due to Messrs. W. C. Gall, W. D. Whiteman, R. T. Slee, F. Voss-Smith, E. N. Holder, W. R. Broad, F. Thomas, A. Black, W. B. Dow, W. J. Turner, and other mine officials, for the excellent observations made by them in their respective mines, and for their generosity in making such observations available to the Department of Mines, New South Wales. It is desired also to state the great indebtedness of this paper to the recent work of E. J. Kenny, Geological Survey, Dept. of Mines, New South Wales.

Conspicuous among the many important questions which perplex the student of Broken Hill rock and lode occurrences may be mentioned:

(i) What is the nature of the geological structure containing the Broken Hill "Lode"?

(ii) Is the "lode" a replacement body, or a series of "pressure" lenses?

(iii) What was the method of transport observed by the ore bodies and of the associated igneous rocks in the journey from their source, or sources?

(iv) How did the "lodes" and the associated igneous rocks accommodate themselves to their containing structures?

(v) Does the study of the "lodes" throw any definite light upon igneous intrusive processes?

The ground broken in this article, and its forerunners,[5] is in-

[3] Andrews, E. C., Memoirs (Geology) Geological Survey, N. S. W., No. 8, 1922; also Supplement, 1923.

[4] Broken Hill District: Recent Mining Developments. Annual Report, Dept of Mines, N. S. W., 1927, pp. 121–130; also Annual Report, 1928, pp. 119–131, with numerous text figures.

[5] Andrews, E. C., "The Geology of the Broken Hill District," Dept. of Mines, N. S. W., 1922. Broken Hill Memoirs (Supplement), Dept. Mines, N. S. W., 1923. "Igneous Intrusions and Ore Deposits," *op. cit.*

tended to be in the nature of suggestions for students of igneous processes within the zone of rock flowage even if the inferences drawn from the field occurrences differ in some measure from long-established ideas concerning igneous intrusions.[5-a]

History of Progress of Ideas Concerning Origin of Broken Hill Lode.

A study of the Broken Hill report of 1922 illustrates the gradual growth of ideas concerning the structure and origin of the Main Broken Hill Lode.

The official geologist of 1884, from a study of the lode outcrop, considered the deposit to be a true lode of tabular form with definite and persistent dip. Working on this principle a bore was sunk in the "hanging wall" of the deposit, so that the lessees of an adjoining block to the northwest of the Broken Hill Proprietary Blocks might ascertain the depth at which a vertical shaft sunk at that spot might intersect the lode. The estimated depth for the intersection was 2,000 feet. The vertical boring, however, failed to reveal the presence of a commercial lode, and at a later stage the prospectors of the Broken Hill Proprietary ascertained that the great lode was "bedded"; that it was following a great contortion in the country rocks; and that it had doubled back on itself. Thereupon, among official geologists, and among the mining companies, arose the idea of a saddle-reef origin for the lode, or deposition in a great open cavity developed within the arch of a fold.[6] This conception was extended later to include deposition in pre-existing cavities in the troughs of folds. Subsequently, the influence of drag-folding and of replacement was appreciated, and, moreover, the inability of the postulated caverns to remain open, while awaiting possible visitations from wandering ore-bearing solutions, was appreciated by the mining engineer. Still more recent observations have shown that the rôle played by

5-a A splendid introduction to the study of the igneous and metamorphic rocks of Broken Hill is contained in the reports by Drs. W. R. Browne and F. L. Stillwell, forming appendices to "The Geology of the Broken Hill District," *op. cit.*

6 Jaquet, J. B. (also appendix by E. F. Pittman), "Geology of the Broken Hill Lode," Geology No. 5, Mem., Geol. Surv. N. S. Wales, 1894, pp. 62 and 138.

replacement has perhaps been over-estimated and that the part played by growth as " pressure lenses " has been under-estimated and moreover that both " hanging " and " foot " walls have been buckled and crumpled on each other with production of strain zones along the steeper limbs of the folds. Kenny's numerous figures in the Annual Reports of 1927 and 1928 illustrate the idea also that ore deposits have been produced on both sides of a medial zone of strain. In many ways, however, the figures illustrating Jaquet's [7] able report indicate the general form of the ore bodies in cross section, that is, as enormous " pressure lenses," " saddles," or phacolithic masses.

With this historical introduction it is proposed to proceed to the inductive method of presentation, namely, the assembling of the results of a great number of field observations, and from these to draw some general inferences.

Sedimentary and Igneous Rocks.

The " oldermass " of the Broken Hill area is a low shield about 60 miles in length and 20 to 30 miles in width. It dips gently under alluvial plains to the south but is separated from the alluvium to the west by a warp-and-fault scarp, having a maximum elevation above the plain of 800 to 900 feet. To the north and east it disappears under late pre-Cambrian formations. The shield is trenched by deep ravines in the areas of maximum topographic relief. Such relief appears to be due to Late Tertiary faulting.

In order better to appreciate the main geological structures an observer may be imagined approaching Broken Hill in an aeroplane from a great height. This area, moreover, is to be conceived as one from which the mantle of soil and subsoil, together with the topographic irregularities, have been planed off, resulting in the production of a smooth and polished rock surface.

The observer would note a central area, about twelve miles in radius, exhibiting a series of subparallel dark and light bands or zones, all markedly contorted and puckered, and appearing to

[7] *Op. cit.*

have been drawn out, or stretched, suggestive of bands or strips of plasticene which have been weighted down moderately, but with lateral support and then subjected to powerful pressure, slowly applied, from a lateral direction. Across these, in side-stepping arrangement, would be seen a network of dark rock-bands of basic type. The observer would be struck at this peculiar association. In the one group he would note the existence, side by side, without sign of actual mutual interpenetration, of a series of sedimentary and igneous rocks, all apparently at one time plastic and apparently frozen in the act of soaking or melting into each other, the other cutting clearly across the trends of all the others and showing neither macroscopic sign of stress nor of chemical alteration.

A close examination would reveal to him the fact that the parallel and subparallel curving bands are composed of sillimanite-biotite-garnet gneisses, intruded by pressure lenses (with a sill-like habit) of augen-gneiss, granulite, pyroxenite gneiss and pegmatite, with *lit-par-lit* injections of gneiss, pegmatite, and highly siliceous material, the whole giving the general appearance of an area of " migmatite."

From this central area the intensity of action appears to have died away, generally, in all directions, the sillimanite-biotite-garnet gneisses suggesting a gradual passage into phyllite, andalusite and chiastolite schist, silky slate, and altered sandstone, in all of which traces of bedding planes are abundantly preserved. Augen-gneisses also are represented in this extra-central area by more massive forms of gneissic granite, by alaskite, by " amphibolite " and by coarse pegmatite, all of which show signs of slight blunt intrusion into the associated sediments. The pegmatites of the central area exhibit magnificent perthitic intergrowths and a pronounced development of graphic growths. Exceptional features are the sillimanite-gneisses of the more western portion of the Broken Hill Shield, suggestive of local intense metamorphism, associated with marked pegmatitic intrusion. The later cross-dikes of basic composition appear to be relatively abundant in the highly altered central area. In some portions of the central area, certain peculiar aplites have been regarded as replacements of sedi-

ments. This is perhaps similar to the striking phenomena of apparent replacement recorded by Quirke [8] for the Killarney gneisses and migmatites (Canada), where, as he states, "the end product of the alteration of all the sediments of the Huronian series so far studied, seems to approach a common type, a granite gneiss low in dark minerals."

The area also appears to be one similar to those which Kato considers as representing ancient deep-seated centers of activity, which may well be considered as having given rise to energetic volcanoes at the surface during that period of activity.

Throughout this area of most intense entry of foreign material, as igneous intrusions, the observer would recognize the numerous "lodes" of the Broken Hill type, all conformable, apparently, to the bedding planes of the associated paragneisses, but exhibiting most fantastic forms, such as corrugated sheets, phacoliths, "saddles" of ordinary and inverted types, and "pressure" lenses associated with pronounced replacement phenomena.

Beyond the central area of sillimanite-garnet gneiss, the observer would note the prevalence of other "bedded" ore deposits, nevertheless lacking the size and bulging appearance of those of the central area, and differing in mineral association from them, as shown below.

This "oldermass," together with its peculiar ore deposits, is believed to be early pre-Cambrian in age. The problem of the origin of the lodes is considered below.

It was during the pre-Cambrian period that the region suffered to such an extent from denudation that the erstwhile deeply-seated rocks of the zone of flowage were exposed at the surface. Our observer thereby had been enabled to appreciate the association of minerals and structures seen by him as end results of the activities in the abyssal chemical and physical laboratory of that period, the signs of the initial and intermediate steps in the physical and chemical processes having been obliterated in great measure. The region sank and a thick mass of terrestrial sediments known as the Torrowangee, Poolamacca, and Corona series, consisting

[8] Quirke, Terence T., "Killarney Gneisses and Migmatites," *Bull. Geol. Soc. Amer.*, 1927, pp. 753–763.

of conglomerate, quartzite, sandstone, shale, mudstone, magnesian limestone, and tillite, was deposited upon the strongly-denuded "oldermass."

These so-called late pre-Cambrian sediments were folded strongly near and beyond the margins of the "oldermass" or ancient shield, but upon the exposed portions of the ancient basement itself they lie almost unaltered and in gentle folds except near the unconformity itself, where certain of the members appear to have moved relatively to the rigid basement and have been converted there to schists.

The quartzite beds have not been affected thus, but the heterogeneous mass of tillite has been strongly affected at its contact with the basement. This alteration, however, does not appear to have extended more than one hundred feet stratigraphically above the base.

In the Poolamacca and Corona Series there are no igneous intrusions immediately overlying the ancient basement of the Broken Hill, or Willyama, Series, but away from the shield it is not at all uncommon to find basic volcanic lavas, with granitoid, and hypabyssal intrusives within the series. These later pre-Cambrian types, however, overlying the ancient inliers, are traversed by enormous white quartz veins and masses, together with ferruginous "pressure" lenses.

Field Observations: The Lodes.

Age.

The upper "pre-Cambrian" tillite contains erratics, or large fragments, of certain of the ore deposits, and the general field evidence indicates that the Broken Hill ore deposits were formed in the deeper portions of a series of compressed folds and that they were exposed and overlain by late pre-Cambrian sediments after repeated elevation and prolonged denudation.

Distribution.

The distribution is peculiar. The larger deposits occupy the zone, or area, of maximum alteration, and they are more ir-

regular in general form than those occupying the less altered rocks of the old shield.

The lead-zinc sulphide deposits constitute the larger "lodes" of the sillimanite-garnet area (central area) whereas zinc sulphide and zinc spinel are practically absent from the outer zone of less alteration. The platinoid minerals are associated with an outer arc of "lenses" and "sills" of serpentine and limburgite. Tinstone and wolfram occur in greisen lenses along another outer and northerly arcuate zone.

Method of Occurrence and Mineral Association.

Method of occurrence.—The ore-deposits or "lodes" belong to the "bedded" type, being conformable with the bedding and foliation planes, respectively, of the associated paragneisses and orthogneisses. The general forms assumed by the "lodes" are phacoliths, saddles, both of ordinary and inverted types, "pressure" lenses, *lit-par-lit* injections, banded replacements, and sills. This conformation to the associated structures is extended to the crinklings and puckerings of the associated country, except in the cases where a massive "pressure" lens has dragged, puckered and crinkled an adjacent group of thin beds of the paragneiss.

In the area of maximum alteration of the sediments, the lodes are larger than in the outlying arcs or zones. Examples are the main Broken Hill Lode and the Pinnacles, the latter being a pocket edition of the Broken Hill Lode, somewhat resembling the Main Lode if it should be viewed through the wrong end of a telescope. The lodes within the outer portion of the shield are relatively small, and regular in shape, nevertheless conforming to such convolutions as not infrequently occur in the foldings of the associated schists or gneisses.

A consideration of the general form, and structure [9] of deposits such as the Main Broken Hill Lode or the Pinnacles Lode appears to throw light on problems not only of ore entries but also of igneous rock intrusions. The features in this connection which are of especial interest to the mining geologist at Broken Hill

[9] The mineral composition is considered below.

are the variable form and size of the lode outcrops, combined with the apparent absence of lode outcrop from various portions of the ore-bearing zone. A preliminary reconnaissance of the field associations indicates the existence of a long, relatively narrow zone of alteration, containing lenses of ore alternating with barren patches along the general strike of the ore-bearing zone. A closer examination yields additional information. Thus the ore patches which are lenticular in place are observed to be "pressure" lenses in great measure, but they represent also the replacement of "dragged" schist and gneiss in considerable degree. The large lenses and replacement masses of the Broken Hill Lode and its extensions are associated with zones of crushed material (now silicified) the pre-lode movements consisting of sharp folding with local slipping and "dragging" of certain rock members over each other, nevertheless maintaining apparent conformability. In places the schists, or paragneisses, exhibit no sign of faulting, as though the slipping and dragging of the altered sediments had been markedly differential, actually showing dead (null) spots or points of zero movement at certain places.

In the zone of the silicified crush itself "pressure" lenses are very prominent, whereas replacement is a prominent feature in the "dragged" series. Furthermore the formation of the larger "pressure" lenses in the Main Broken Hill Lode appears to have been accompanied by "dragging" or puckering and crinkling of the adjacent sillimanite gneiss.

Again, the lode outcrops may have no visible relations with each other, save that they are similar in form, that they are similarly situated, that they possess the same peculiar mineral assemblages and associations, that they are arranged along the same general plane of fold "dragging," and that as the "lodes" themselves are approached from the barren crush zones, signs of discoloration and development of peculiar blebs of quartz become apparent. The field geologist, confronted with this feature repeatedly in his mapping of lode outcrops, naturally asks himself by what mechanism material in great quantity and derived apparently from a common source, has been transported so as to be assembled finally as huge lenses and replacements of coarsely-

textured mineral aggregates along independent planes or narrow zones, and nevertheless reveal no trace or sign of its passage along the barren portions. Mining operations indicate the complete isolation of each "lode" or lens from others occurring within the same zone. In every instance the "lode" or lens is conformable with the associated bedding planes with suggestion of wedging (feathering) out between contiguous bedding or foliation planes.

Broken Hill is an example of the great assistance which mining geology may render the cause of general geology, because the mining engineer is in a position to observe the contact of ore body and country rock in fresh exposures during the progress of ore removal, whereas the areal geologist in non-mining areas must rely on relatively rare and indistinct contacts and exposures. The field evidence of the area under consideration, taken in conjunction with the mine exposures, suggests that the material composing the deposits had a common source, whether solid, liquid, or in other state; that they do not represent lateral segregations from the country rocks; that they appear to have risen under enormous head and forced the bedding or foliation planes apart; and that they came to rest in a "pressure" slack, but nevertheless were enabled to pass from point to point under pressure in such a manner as to leave no visible trace of such passage. A study of the associated igneous rocks suggests a similar action in their case. Indeed, all appear to be "pressure" lenses, injections without visible connection with feeding source, and which also have altered the associated sediments to the migmatite stage in many places.

The complete relations, in structural form, of the great Hanging Wall [10] bodies and the adjacent paragneisses have never been established. The engineers and surveyors of the mining staffs [11] about twenty years ago were divided into two groups, namely, those who considered the lodes as being strictly conformable at all points with the associated gneisses, and those who considered

[10] Broken Hill Report, 1922, *op. cit.* Lodes and sections.

[11] Report of Broken Hill Geological Sub-Committee, *Trans. Aust. Inst. Min. Eng.*, vol. XV., 1910.

that the Hanging Wall bodies wedged, or passed out gradually, between the planes of the gneisses. The peculiarities of the replacement phenomena, coupled with the exigencies of commercial mining operations, had never permitted this point to be settled by direct observation. At all points where the Hanging Wall bodies had been observed in actual contact with the associated gneisses, they were observed to be conformable with the associated bedding and foliation planes of the gneisses. Of this phenomenon the mines offer innumerable examples, and each stope speaks eloquently of this structure. But to the west, where the great convoluted bodies, which constitute the mainstay of the Main Lode itself, and where the ore might have been expected to die away between the ancient bedding planes, there the ore is extremely siliceous or garnetiferous and exploitation ceases to be profitable. For this reason, mining operations cease at these points. In the ordinary work of ore exploitation, however, many mining openings have been made, an examination of which would have shed considerable, if not indeed sufficient, light on this interesting problem for its satisfactory solution; nevertheless, owing to the lack of trained observers on the spot when such openings were made, these occurrences have remained undescribed inasmuch as, in the interests of safety, close-filling follows immediately upon stoping operations at Broken Hill.

Since the year 1923, however, many experienced engineers and other mining officials along the Broken Hill Line of Lode, have made valuable observations,[12] and Mr. Kenny, in the publications cited herewith, submits a brief summary statement of these observations together with those made by himself.[13]

Mr. Kenny considers that the so-called Foot-wall Lode occupies the site of a silicified crush zone, that it is the main lode channel, but that large ore bodies exist also on the eastern, or footwall side again of this main channel.

[12] E. J. Kenny, Ann. Rept. Dept. of Mines, Sydney, 1927, pp. 121–130; also 1928, pp. 119–132, with numerous figures.

[13] At the request of the Broken Hill Companies the Department of Mines, New South Wales, has approved of the correlation, by one of its official representatives, of geological observations conducted along the Lode by the Companies. Mr. Kenny at present is conducting this important work.

The western ore masses, according to him, are essentially anticlinal in form, whereas the eastern counterparts possess a synclinal section in general. He infers that the ore deposits disappear between bedding planes to the west. His text figures, based on actual measurements in the mines, appear to confirm this.

Turner,[14] as a result of long and detailed study, during residence, of the Pinnacles area, has been enabled to give a clear picture of this smaller homologue of the Main Broken Hill Lode.

Turner indicates the existence of a four-fold arrangement of rock types for the area:

i. A persistent sill of "amphibolite."
ii. A well-marked and resistant sill of aplite, subjacent to a zone of heavy crush, and this, in turn, capped by
iii. Deposits of banded siliceous ironstone (magnetite, hematite, and quartz).
iv. Schists (paragneisses) highly compressed, lying "a little below (stratigraphically) the amphibolite-aplite zone, and including the zinc and silver-lead lodes."

Turner notes the constant association of the lodes with a pegmatite containing green and greenish-blue feldspars, the pegmatite following a definite zone in the schists. As a result of his field observations he concludes that the siliceous ironstone deposits are replacements of the upper portion of the sheared aplite.

The "lodes" are two subparallel deposits, separated by a narrow belt of paragneiss. The general appearance of the lodes is that of saddles and sills, and Turner considers that they originated in ore entries along a zone of weakness formed along a plane of gliding or dragging, with production of sill or phacolithic forms among the "dragged" sediments, both in the hanging and foot walls of the main lode channel. The deposits are bedded and show thickening within the crests and troughs of the folds. In places the two lodes join mutually by replacement of the associated and erstwhile separating sediments. They are known respectively as the Silver-Lead, and the Zinc, Lodes. Both are

[14] Turner, W. J., "Notes on the Geology of the Pinnacles Mine and District," *Proc. Aust. Inst. Min. and Met.*, 1927, pp. 297–312 (1 pl., 15 illus.).

conformable with the belt of "pegmatitization," which, in turn, conforms to the bedding planes of the associated sediments.

Mineral Association.—The general form of the deposits, as "pressure" lenses, "sills," "saddles," injections, and replacements, appears to bear a definite relation to the abundance of dense silicates and oxides in the various lodes.

It has been shown [15] that the ore deposits, in the area of maximum injection, are intimately associated with a pegmatite with peculiar green and bluish-gray feldspars, with rhodonite, manganese-garnet, fluorspar, zinc-spinel, calcite, magnetite, and residual silica, whereas the lodes, away from the central area, have a characteristic gangue of carbonate of iron. A fluorspar gangue, however, occurs somewhat abundantly along the northwestern strip of the "oldermass" of the Willyama, or Broken Hill, gneisses. Zinc sulphide occurs abundantly in association with the lead sulphide lodes of the central area of injection, whereas zinc sulphide is characteristically absent from the deposits of the more marginal areas.

The association of the minerals within the individual lodes themselves is also significant. Kenny [16] credits W. C. Gall and W. D. Whiteman with the observation as exemplified below of a definite zonal disposition of minerals in the mines of the northern end of the Main Broken Hill Lode.

This "zonal disposition of the ore material and gangue minerals from the underwall upwards in the lode system is as follows:

i. Rhodonite masses.
ii. Sulphides with rhodonite predominant in gangue.
iii. Dense sulphides, devoid of banding, with enhanced silver values. This type is known as "magma" ore by Gall.
iv. "Banded sulphide ore predominantly siliceous. A replacement type with 'garnet sandstone' and green feldspar common on the margins."

Not only is this crude zonal disposition found in vertical succession but it obtains also in places along the lower levels of mines such as the large North Mine.

[15] Andrews, E. C., Broken Hill Memoir, 1922, pp. 156, 157, 169.

[16] Kenny, E. J., Ann. Rept. Dept. Mines, N. S. Wales, 1927, pp. 121–130; also Ann. Rept. 1928, pp. 119–132.

In the important Zinc Corporation Mine at the southern end of the Main Lode, as worked, Kenny points out that the zonal arrangement, from the lower levels upwards, is:

i. Rhodonite and rhodonitic ore.
ii. Dense sulphides with high silver content.
iii. Calcitic ore.
iv. Siliceous replacement ore.

In the large South Mine, however, which lies immediately to the north of the Zinc Corporation Mine, garnet of the manganese type most commonly takes the place of the rhodonitic masses in No. 1 division above. The Central Mine adjoining the South Mine on the north, possesses a mineral association very similar to that of its adjacent southern neighbor.

This is merely a very general statement concerning the peculiar mineral associations within the Main Lode. Thus (iii) above in the North Mine is described as "dense sulphides devoid of banding," whereas it is well known, in Broken Hill mining, that the term "dense sulphides" is used merely in a relative sense, the sulphides themselves in this division having gangue minerals of rhodonite, fluorspar, garnet, and calcite. It is known, moreover, as observations are carried north and south for miles along the main zone of ore deposition from Broken Hill as a center, that the dense silicate and calcite gangue passes into one which is more ferruginous and contains more free silica.

Kenny also describes a peculiar zone occurring near the footwall of the main ore body of the North Mine which is composed of quartz and feldspar, with bands of garnet having the appearance of a finely-textured sandstone. Rhodonitic material, in the form of pressure lenses, exists also in the footwall country of the North Mine, near the lode itself, on the 1700-foot level.

Another feature of considerable interest, noted by Kenny and Holder,[17] is the peculiar material association occurring in the zone of gneiss separating the Main Lode from the parallel Zinc Lode in the Zinc Corporation Mine. This is revealed in the exploratory crosscuts (and in the diamond drill cores) connecting the

[17] Ann. Rept. Dept. Mines, N. S. W., 1927, p. 129.

two ore bodies, where considerable faces of rock are exposed, consisting mainly of "quartzite," "garnet-sandstone," pegmatite and "green rhodonite" with bands of lead and zinc sulphides and a sporadic development of pyrites, near the western margin of which the Zinc Lode occurs. As Kenny points out, all this represents replacement material connecting the widely-separated, but parallel, Main and Zinc Lodes.

Beyond the Main Lode, to the west, it is customary to find impregnations, and other developments, of gahnite (zinc spinel), "green rhodonite," pegmatite, and siliceous material. From a general consideration of the location of these minerals, and their obvious genetic association with the lode minerals, the Broken Hill observers long since came to the conclusion that the Main Lode conformably rides an arch (or trough in places) of paragneisses, in places suggestive [18] of the sliding-down of a bannister rail by a child, where the straddling legs and the body represent the ore bodies, the bannister representing the country-rock with its sediments bent into arches and troughs. In this form the rhodonitic masses keep close to the bannister rail, while the less dense silicates occur in the upper portions. The mine officials consider that the lode was once much greater in extent than at present, rising formerly high above the present outcrop, and subsequently suffering great reduction in vertical extent by denudation. In this view a plunging fold is seen as revealing "dragging" action, the apices of the "drag folds" opening to accommodate "pressure" lenses of ore while strong replacement action is proceeding from these "magma" bodies. The crest of the plunging fold is itself corrugated and forms a "null" spot whereas the plungings of the fold to the north and south of this central arch allow correspondingly increased action of dragging and of the formation of "pressure" lenses. The upper portion of the original ore mass followed a course which is in rough sympathy with the general form assumed by the fold and its undulating plunges to the north and south. The rhodonitic mass occupied the lower position. Above it were deposited the garnet masses, the dense sulphides, the fluorspar, the calcite, and so on,

[18] Analogy employed first by Whiteman (British Mine).

while the upper portions partook more and more of replacement types, resulting in pegmatites with green feldspar, zinc spinel, "quartzite," and quartz. Certain of these, such as the pegmatite, assume the form of pressure-lenses in places. The whole ore deposit, the commercial with the non-commercial, considered in longitudinal section, would have the general appearance of a giant fan opened but pressed out of shape to such extent that its arch was flattened materially, and its simple curvature ornamented, or broken up, with rippling undulations. The base of the fan would represent the paragneisses, while the more extensible portion would represent the ore bodies passing away at the upper portions into quartz, pegmatite, silicified gneiss, sulphide impregnations, and so on, and dying away finally between bedding planes and along zones of sedimentation.

Turning now to the Pinnacles for possible additional information concerning the origin of the Broken Hill Lodes, it is important to note Turner's observations. He points out that the Pinnacles [19] ore deposits consist of "lode injections and replacements" including "lode" pegmatites (with green feldspar), "lodes" containing sulphides of zinc, copper, iron pyrites and pyrrhotite, and "lodes" of silver-lead with a heavy silicate gangue. Manganese-pyroxene, at the Middle Pinnacle, is associated with iron, lead and silver, and zinc minerals.

The first invasion, according to Turner,[20] was a "lode pegmatite" which in its ribbon-like replacements follows "the bedding planes of the schists in all their puckered distortions." They occur also as "pressure" lenses along certain zones, the bedding planes being forced apart to accommodate them. Turner notes that much of the pegmatite is remarkable for the presence of green or greenish-blue feldspars. "This pegmatite follows a definite zone in the folded schists situated a little below the amphibolite-aplite [21] zone, and it includes the zinc and silver-lead lodes."

[19] Ten miles south-south-west from Broken Hill.

[20] *Op. cit.*

[21] T. L. Willan in a personal communication furnishes evidence for his belief that the aplite bands of the northern end of the field are replacements of paragneisses.

The main ore deposits are two, known as the Zinc and the Silver-Lead Lodes.

The Zinc Lode, which consists of zinc-sulphide with silica and other siliceous material, has replaced both the pegmatite and the paragneiss in part. Manganese garnet is comparatively rare. Iron and copper sulphides occur in appreciable quantities, as also pyrrhotite. Silver-lead minerals are rare and appear to have entered after the zinc and other sulphides, as these in turn succeeded the pegmatite.

The silver-lead lodes invaded the footwall side of the "Lode Channel" and they are arranged parallel to the bedding planes and, according to Turner, they are of the nature of replacements, both of the schists (paragneisses) and the pegmatite. They are separated from the Zinc Lode by thin beds of schist in places silicified and of irregular thickness. In some places also the replacements penetrate the "drag-folded" schist and are in contact with the Zinc Lode.

Summary and Conclusions.

Summary.—(1) The igneous rocks of the Willyama or Broken Hill "oldermass" belong to two periods of intrusion:

a. The period of marked folding where the more deeply-buried sediments affected were subjected to severe compression on all sides.

b. The period of relative stability consisting of periods of gently epeirogenic movements following on long-continued denudation. By this means the old "bedded" igneous types have been brought into the superficial zone or layer of relatively negligible compression.

The igneous rocks of this second period consist in the main of true dikes, which traverse the strike both of the sediments and of the igneous gneisses, in all directions.

(2) The ore deposits appear to be phases of igneous intrusions belonging to the closing stages of the "bedded" form of intrusion. The pegmatite, with green feldspar, appears to have been a forerunner, as it were, of the ore deposits proper. All the ore

deposits are, characteristically, conformable to the associated bedding planes indifferently whether they are of the "pressure" lens, "saddle," or replacement, type, and all are suggestive of injection phenomena.

(3) All the numerous ore deposits examined appear to end vertically, as well as laterally, either against or between bedding planes. They are facts of form which appear to be completely isolated from each other, whether considered in section or in plan. On the other hand their general form, their structural relations, and their mineralogical composition, all indicate that they have been introduced into the Broken Hill area under great pressure and that they are not mere segregations from the local country rock. From the "pressure" lenses and other peculiar injection forms, replacement action has extended into the wall rock with varying degree of intensity. Thus in certain places the massive ore abuts almost directly against ordinary sillimanite gneiss, whereas, in many other places, the action on the walls has been such as to suggest that they have been soaked in a heated pegmatite bath for an extended period of time so as to produce an appearance suggestive of the advanced replacement of the wall paragneisses by pegmatite.

(4) No sign of feeding source has been detected for the igneous rocks. This has been established clearly for the ore deposits themselves, owing to the enormous scale on which mining operations have been, and are being, conducted within the Broken Hill area. The lodes are noted to disappear abruptly in depth as they are worked along the undulating pitch of the enveloping fold. In plan, the deposits occur as isolated lenses or irregularly-shaped "bedded," masses, all of which are arranged along a structural zone (gliding plane or drag zone of a fold limb), and are separated from each other by stretches of barren country rock, although the general field evidence suggests to the trained observer that the material forming the present ore deposits may well have traversed these same barren portions which in turn are situated along the same structural zone of stress.

Conclusions.—From the above summary of our present knowledge it appears permissible to infer that the Broken Hill region

during the earlier portion of pre-Cambrian time was affected by a movement of strong folding, in which there was a definite tendency on the part of the compressed sediments to escape lateral thrusting by vertical movement, that is towards the zone of relatively negligible pressure. In other words there was a strong reaction towards the surface of the earth. The more deeply-seated portions, however, that is those overlain—and hence heavily weighted—by thick masses of sediments, were subjected to powerful pressure not only from the sides but from above. Alpine ranges appear to have been formed by the resultant vertical action, the growth of the mountain crest being balanced, or compensated, by the production alongside of a corresponding structural trough or geosyncline. An earth undulation was formed thus, consisting of a corrugated mountain crest, together with one or more geosynclines. The mountain ranges themselves appear to have been, in the main, an expression of the resultant relative relief from the pressure exerted outwards beneath the sinking trough. This rise of the alpine crest in undulatory form was modified locally by overthrusting towards the sinking portion. The relative relief by axial uplift offered an avenue of escape for material which may have been already in a molten state or which may have assumed a mobile form merely as the result of local decrease of pressure. The material, moreover, may have had its source indifferently under a trough or under a rising crest. The passage into the rising mass was effected thereby with corresponding increase in the vertical movement.

The field evidence at Broken Hill indeed suggests that:

i. The igneous rocks rose in the form of injections.

ii. The material forming the injection had a double source, one beneath the sinking trough, the other beneath the rising complex crest.

iii. The material was erstwhile solid and was rendered liquid only by the relief of pressure attendant on the resultant rise of the crest of the earth undulation under consideration.

The head to which this igneous material was subjected was so

enormous, and the physical state in which the potential igneous rock existed was such, as to enable it to traverse the bedding and crush planes in the sediments, and to accomplish this work so gradually, the time factor being very large, as to force bedding planes apart, coming to rest finally either in "pressure slacks" or against strong impervious rock members possibly far removed from their source of origin.

The field study of the igneous rocks and of the ore deposits suggests, moreover, that they may not even contain the same mineral assemblages, nor present the same general appearance which they possessed during their passage, under the enormous head suggested, to the "pressure slacks" or to points whence escape was impracticable.

The latest stages of igneous intrusions appear to have been attended with increased mobility of the igneous material, resulting in injection and replacement, both of sediments and the earlier orthogneisses by aplite, pegmatite, and ore deposits.

These are the inferences to be drawn from an examination of a single area such as Broken Hill, but it is considered also, from a general review of the available literature,[22] that the phenomena recorded here are not peculiar to the Broken Hill area but that regions elsewhere also, such as the Canadian Shield, the older rock groups of the greater Appalachian belt, the Baltic Shield, Peninsular India, the Siberian Shield, together with the "older-masses" of China, Australia, and Brazil, may be expected to reveal rock and mineral assemblages associated with structures similar to those described above.

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[22] Quirke, T. T., *op. cit.*, and literature cited therein for igneous replacements.

SEDIMENTATION IN THE CHANNEL ISLANDS REGION, CALIFORNIA.[1]

PARKER D. TRASK.

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INTRODUCTION.

SINCE July, 1926, the American Petroleum Institute has been conducting an investigation of the conditions under which sediments that in the future may be source beds of petroleum are now accumulating. A preliminary phase of the work was the ascertainment of the distribution of organic matter in various types of marine sediments,—the object being to locate regions in which potential future source beds of petroleum are now forming. One of the most favorable of

[1] This paper contains preliminary results of an investigation on the "Origin and Environment of Source Sediments," listed as Project 4 of the American Petroleum Institute Research Program. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by Mr. John D. Rockefeller. This fund is being administered by the Institution with the coöperation of the Central Petroleum Committee of the National Research Council.

such areas is the Channel Islands district off the coast of Southern California. It is the object of this paper to present a preliminary account of the detailed investigation of this region. Final and more complete results will be included in the final report of the project.

ACKNOWLEDGMENTS.

A considerable amount of the material presented in this article is based on work of people who have either been associated with the project or have coöperated with it. The writer wishes to express his appreciation of this assistance and to give proper credit for all work done.

Harald E. Hammar, Research Assistant of the American Petroleum Institute, at present associated with the writer in analyzing the constituents of the various types of organic matter in sediments, performed about one-half the nitrogen, carbon and carbonate determinations, and Henry B. Schulhoff made most of the remainder. J. P. Koontz did about three-fourths the work for the mechanical analyses and he also made some of the ignition tests; but most of the ignitions were performed by Fanniemae C. Trask. Samples 410 to 417 and 425 to 429 were kindly collected by Eric G. Moberg, and W. W. Valentine helped gather samples 651 to 681. Mechanical analyses of samples 2 to 26 were made by the U. S. Bureau of Soils.

Opportunity to procure samples 2 to 26 and 410 to 429 was extended by T. Wayland Vaughan, Director of the Scripps Institution of Oceanography, who made the Institution's boat available for collecting during the summers of 1926 and 1928. The writer desires to express his appreciation to W. L. Valentine, president of the Fullerton Oil Co., for the loan of his yacht, "Volador", during August, 1929, for the purpose of gathering samples from the deeper waters of the Channel Islands region.

The sediments described in this paper were studied in the laboratories of four institutions, which the writer wishes to thank for their hospitality. These laboratories are: The

Scripps Institution of Oceanography; Chemistry Department, Stanford University; Laboratory of Soil Science, New Jersey Agricultural Experiment Station; and the Frick Chemical Laboratory, Princeton University.

The writer desires also to thank the members of his advisory committee for aid and criticism of the work. This committee is composed of Alex. W. McCoy, chairman, Austin H. Clark, W. A. J. M. van Waterschoot van der Gracht, T. Wayland Vaughan, and Selman A. Waksman. Mention should also be made of the helpfulness of David White and K. C. Heald of the Central Petroleum Committee of the National Research Council.

GENERAL REMARKS.

Description of the Region.—Along most of the Western Coast of North America the continental platform is narrow, but off southern California between Pt. Concepcion and San Diego it expands to a width of about 150 miles. This is effected by an embayment of the coast line rather than by a retraction of the abyssal deeps. The floor of the platform in this area is very uneven and consists of a series of ridges and depressions. Some of the ridges rise above the surface to form islands and many of the depressions are closed basins.

Four of the basins are discussed in this paper. They are the Santa Barbara basin, between the mainland and the row of islands south of Santa Barbara; the Santa Monica basin, southwest of Santa Monica Bay; the Catalina basin, west of Catalina Island; and the Santa Cruz basin, south of Santa Cruz Island.

The depth of water ranges from a little over 300 fathoms in the Santa Barbara basin to more than 1,000 fathoms in the Santa Cruz basin. This latter is about the maximum depth attained on the continental platform in this area. Notwithstanding the depth of water in these depressions the term "continental platform" is appropriately applied to this region, as these basins are separated from the abyssal deep of the open ocean by a zone of shallow water of depth ranging from 100 to 200 fathoms.

The region is clearly one of diastrophic activity. This is attested by the raised beaches and terraces on the islands, by the series of submerged valleys along the coast, and the closed nature of the basins. It may be argued that some of the depressions are closed because of sedimentation, but the closure of Santa Cruz basin south of Santa Cruz Island is at least 2,700 feet, and that of the Catalina Basin, west of Catalina Island, is about 1,000 feet. The magnitude of these closures indicates diastrophism.

Location of Samples.—The location of the samples that form the basis of this paper is shown in Fig. 1. Numbers 414, 665,

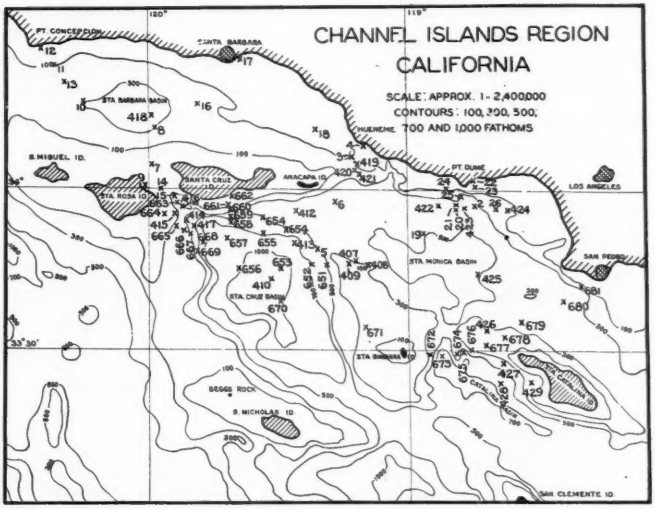

FIG. 1. Location of Samples.

666 and 671 consist of shale, probably of Monterey Miocene age, overlain by a thin veneer of fine- to medium-grained sand. The sandy sediments were collected with a large telegraph snapper, and the silt and clay deposits with a modified Ekman sampler, which procured a core about a foot in length. The finer sediments are greenish-gray in color and have a water

content of about 60 per cent. In none of the core samples of the silts and clays was stratification observed. In fact, in none of the silts and clays gathered by the writer in any region from which he has collected was bedding evident in the fresh sample. This apparent lack of stratification in these mother rocks of shales is contributory evidence in support of the hypothesis that the fissility or "bedding" which is so characteristic of shales may not always represent primary stratification, but may often be due to other causes.[2]

RESULTS OF MECHANICAL ANALYSES.

Method of Analysis.—Mechanical analyses have been made on most of the samples shown in Fig. 1. Samples 2 to 26 were analyzed by the U. S. Bureau of Soils by its standard procedure,[3] which separates the sediment into clay, silt, and various groups of sand and gravel. The remaining samples were analyzed by a method [4] which gives the sand and gravel sub-groups and the complete size distribution of all the constituents finer than sand. One of the advantages of this method is that it determines the median diameter, which is the mid-way point in the size distribution, as half the weight of the sediment is composed of particles larger in diameter than the median, and half, smaller. The median tells more about the texture of a sediment than any other single figure, and serves as a very satisfactory means of comparing one deposit with another. In fact it gives a mathematical basis for classifying a sediment as a sand, silt, or clay. If the median is larger than 50 microns, the deposit is a sand, if it is between 5 and 50 microns it is a silt, and if it is less than 5 microns, it is a clay.

Fig. 2 shows the variation in texture of the sediments in the Channel Islands region, on the basis of the median diameter.

[2] See W. W. Rubey, "Lithologic Studies of Fine-grained Upper Cretaceous Rocks of the Black Hills Region," U. S. Geol. Surv. Prof. Paper 165, p. 39, 1930.

[3] L. J. Briggs, F. O. Martin, and J. R. Pearce, "Centrifuge Method of Mechanical Analyses," U. S. Dept. Agric. Bur. Soils, Bull. 24, 1904.

[4] P. D. Trask, "Mechanical Analyses of Sediments by Centrifuge," ECON. GEOL., vol. 25, pp. 581–598, 1930.

The numbers in this figure represent the size of the median in microns, *S* indicates sandy sediments that have not been analyzed, and *B* refers to barren areas. The medians of samples 2 to 26 are estimated from the percentages of sand, silt, and clay, and hence, are less accurate than the others, which are determined directly from the analyses.

Relation of Sediments to Submarine Topography.—The relation of the texture of the sediments to the bottom configuration is clearly shown in Fig. 2. Fine-grained deposits

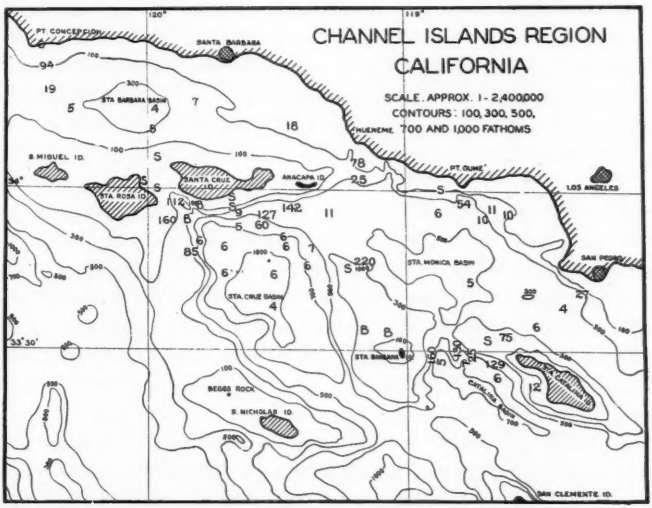

FIG. 2. Variation in mechanical composition of sediments. Numbers refer to median diameter in microns. *S*, sandy bottom; *B*, barren areas.

accumulate in the basins and course-grained sediments form on the ridges and divides. Depth of water, except in near-shore shallow zones, is of slight importance compared with submarine topography. Sediments at the bottom of each of the four basins have median diameters of 6 microns or less but the column of water overlying these deposits ranges from 300 fathoms in the Santa Barbara basin to 1,000 fathoms in the

Santa Cruz basin. On the other hand ridges and slopes between the depressions are characterized by coarser sediments than in the bottom of the basins, even though they lie in much deeper water than do some of the clays on the floor of the shallower basins.

Take samples 672 to 679 inclusive. These represent a very irregular portion of the sea floor. Sample 672 on the relatively steep slope of the northwest side of the Catalina basin, even though the water is 300 fathoms deep, is a well-sorted, fine-grained sand, the median of which is 160 microns. Sample 673, only a short distance away at the bottom of the basin in 725 fathoms of water, is one of the most fine-grained deposits of the Channel Islands region, having a median diameter of 5 microns. Sample 674, some 7 kilometers to the northeast, lies on the summit of a divide between two valleys. The water is over 400 fathoms deep, yet the sample is a fairly well-sorted fine-grained sand having a median diameter of 130 microns. The median of sample 675 in the valley beyond, but above its debouchement on the floor of the Catalina basin is 6.8 microns. Sample 676 on the other side of the valley in water 375 fathoms deep has a median of 25 microns. This sediment is considerably coarser than sample 675 in the bottom of the valley, but is much finer than sample 674, which lies in 150 feet more water on the crest of the ridge between the two valleys. Or to put it another way, the median of sample 676 on the slope out of the valley is four times greater than that of sample 675 in the floor of the valley and is only 1/5 as large as that of sample 674 lying in deeper water on the crest of the divide across the valley.

Sample 677 in 130 fathoms of water on the summit of the broad, nearly flat-topped divide between the Catalina and Santa Monica basins, consists of a fine- to medium-grained sand. Unfortunately an insufficient quantity of this sample was procured for a mechanical analysis. Sample 678 in 200 fathoms, on the slope into the Santa Monica basin likewise is sandy, but it is finer than sample 677, as its median is 75 microns.

This section is typical of the Channel Islands region. The same phenomena occur in the Santa Barbara basin. The median diameters for three successively deeper samples are 94, 13 and 5 microns. Similar to this is the section southward from Hueneme where the progression is 78, 25, 11 and 6 microns. The line from the bank north of Santa Barbara Island, represented by samples 408, 651, 652 and 653, shows the same phenomena. Sample 408, lying in 80 fathoms on the crest of a ridge, is almost a medium-grained sand, as its median is 220 microns. Sample 651 on the fairly steep slope into the Santa Cruz basin in water 500 fathoms deep is nearly as coarse-grained, its median being 140 microns. However, where the slope flattens out near the bottom of the basin the sediments are fine-grained and have medians of about 6 microns.

Apparently below a depth of 700 fathoms in the Santa Cruz basin the fineness of the deposits does not increase. Thus on the slope out of the depression toward Santa Cruz Island, sample 658 in about 650 fathoms has a median diameter of 5 microns. The median of sample 659, in 450 fathoms, is 8.5 microns, but occasional rounded volcanic pebbles up to a centimeter in diameter that occur in the silt matrix were disregarded in computing the median. Sample 660 in 260 fathoms is a fine to medium-grained sand; but no analysis was made because of insufficient material. Sample 661 in 200 fathoms consisted entirely of well-rounded volcanic pebbles two or three centimeters in diameter. The nature of the matrix, if any was present, is unknown. The origin of these pebbles is probably the massive conglomerate exposed along the adjacent coast of Santa Cruz Island.

Over much of the area in the vicinity of the two valleys at the northwest edge of the Santa Cruz basin, no sediments are accumulating on the sea bottom. On two successive hauls in some 200 fathoms of water in the valley between the submerged 100-fathom ridge and Santa Cruz Island the sampling apparatus came up without any sediment and was badly dented. Evidently in this area the bottom consists of hard rock.

Samples 665 and 666 on the slope downward from the shoal south of Santa Barbara Island consisted of a bituminous shale of the Monterey Miocene type overlain by a thin veneer of fine- to medium-grained sand. These shales, though soaked with water, were well indurated. A similar phenomenon occurs in sample 671 on the bank extending northwestward from Santa Barbara Island. The deposit consisted of a thin coating of fine- or medium-grained sand underlain by a bituminous shale.

Moberg [5] quotes losing several pieces of sampling apparatus attached to a single line during a sounding off La Jolla, some 100 miles to the south. It is extremely improbable that so many things could have dropped off during a single haul and the logical inference is that they were scraped away by a rocky ledge on the upward pull.

Cause of Variations in Texture.—Although distance from shore and depth of water are factors affecting the texture of the sediments on the ocean bottom, the evidence presented above demonstrates that in this region they are of minor importance compared with configuration of the sea floor. The generally accepted limit of the influence of waves is 100 fathoms. As practically all the samples come from water deeper than that, variations in texture of these sediments can not be ascribed to such a cause.

In all probability the dominant factor is current action. It is well known that sea water moves. The winds, the tides, and oceanic circulation, all cause translation of masses of water. This motion of water is strongly influenced by the submarine topography. Divides between basins tend to obstruct and deflect its course. The velocity of the bottom currents should be greater over the ridges than on the slopes and in the basins. In fact, due to the internal friction of the water the strength of the currents immediately overlying the sea bottom should decrease progressively from the ridges into the valleys. As the texture of sediments depends among other things upon the velocity of the water in which they

[5] Eric G. Moberg, Private communication.

accumulate, it follows that the degree of fineness of the deposits should increase progressively from the crests of the divides towards the bottoms of the valleys and basins, and this is exactly what occurs in the Channel Islands region.

If one knew the relation of strength of current to the texture of the deposits he might, by means of mechanical analyses of the sediments, be able to ascertain the average velocity of the water over various parts of the sea bottom. Although such inferences at present would be premature, it seems warranted on the basis of the mechanical analyses now available, to assume that the water in the deeper part of all the basins in the Channel Islands region is very quiet—a view in accord with present oceanographic thought. Because of the similarity of the deposits in the Santa Cruz Basin from the bottom up to a depth of 700 fathoms, it may be inferred tentatively that the lower three hundred fathoms of water in this depression is quiescent. On the other hand the absence or scarcity of deposits on the slopes and in valleys leading out of the northwest end of the basin, suggests relatively strong current action in that area.

As Rubey [6] has pointed out and as has been corroborated by the writer, it frequently is possible to disperse fairly completely the constituents of shales. Thus when the laws of sedimentation have been worked out better, it may be possible, by means of mechanical analyses of samples from various parts of a single stratigraphic zone, to ascertain many of the details of the environmental conditions of its formation, which at present can not be determined.

Relative Coarseness of Fine Sediments.—The most fine-grained deposits in this region have a median of about 5 microns. This is true of practically all sediments that the writer and his associates have analyzed from the Pacific Coast. On the other hand samples analyzed by F. B. Walcott and the author from the Orinoco delta, Gulf of Venezuela, Lake Maracaibo, bays of South Texas and bays on the Mississippi delta and even off the mouth of the McKenzie

[6] W. W. Rubey, *op. cit.*, p. 39.

River in Canada, had medians less than three microns and some as low as one.

The constituents of the Pacific Coast samples come from regions of high relief, while those from the other districts are derived from areas of low relief and were transported mostly by large rivers. Sample 260 from the Orinoco delta in 15 fathoms of water, about 20 miles north of the mouth of the river, in the Gulf of Paria, has a median of 1.0 micron, and 25 per cent. of the weight of the sediment is composed of particles finer than .5 micron. Yet the region is one of strong currents. The surface water was flowing at the rate of about three knots when the writer collected the sample. In view of the strength of the current, one would expect the sediments to be coarser, but as the deposits are very fine-grained the most logical inference is that the sea water there contains few coarse particles and consequently whatever is deposited must be fine-grained. Sample 236 from the flood plain of the Mototan River flowing into Lake Maracaibo had a median diameter of 1.5 microns and 25 per cent. of the weight of sediments was finer than .57 micron.

The fineness of all these deposits suggests that the debris transported by the streams supplying these environments of deposition contains a high content of fine particles. As corresponding sediments from the Pacific Coast are more coarse-grained, by analogy it might be inferred that there the rivers carried a lesser amount of fine constituents than did the streams mentioned above.

Many factors influence the size of the particles transported by rivers and the texture of the sediments as they accumulate. Whether the relief of the land supplying the debris is an important factor influencing the texture of the most fine-grained sediments accumulating in an environment of deposition is not yet demonstrated, but the correlation between the high relief and relatively coarse deposits of the Pacific and the low relief and fine sediments of the Arctic, Gulf, and Orinoco delta favor such a hypothesis. If further work substantiates this view, mechanical analyses of past sediments

may throw light on the general relief of the land that supplied the debris.

CALCIUM CARBONATE CONTENT.

The general distribution of calcium carbonate in the sediments of the Channel Islands is shown in Fig. 3. As a rule

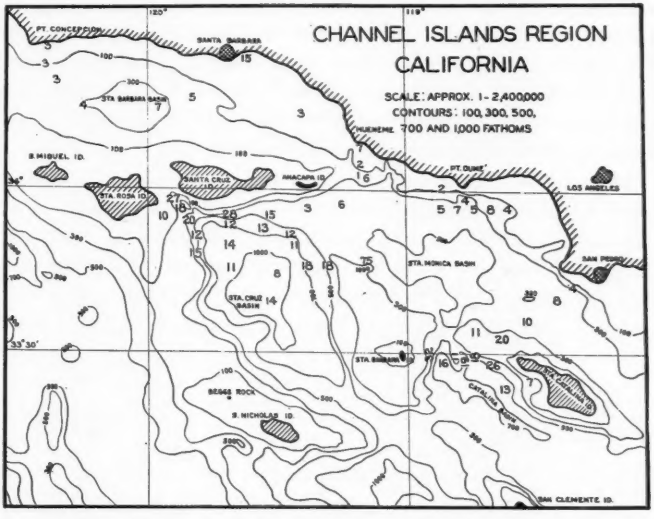

FIG. 3. Distribution of Calcium Carbonate. Numbers refer to per cent. $CaCO_3$.

the calcium carbonate content is less in shallow water than in deep water. This generality even applies to the basins, for in the relatively shallow Santa Barbara basin it is 7 per cent compared with 14 and 16 per cent. in the deep Santa Cruz and Catalina basins. As the organic content of the deposits in the deeper depressions is greater than in the shallower, the relatively high concentration of calcium carbonate in the deeper basins may be due to abundance of foraminifera. Locally in shallow water, as on the 100-fathom knoll northwest of Santa Barbara Island, on the banks northwest of Catalina Island and on the shoals southeast of Santa

Rosa Island, abundance of shells causes the calcium carbonate content to be high.

ORGANIC CONTENT OF SEDIMENTS.

No direct means of determining the organic content of a marine sediment has yet been devised. Soil chemists ordinarily estimate the organic content of soils by multiplying the organic carbon by a factor of about 1.7. In view of the analogy between soils and bottom deposits, until definite evidence to the contrary is adduced, a similar procedure may tentatively be used for marine sediments.

Organic carbon is not determined directly but is the difference between the total carbon and the carbonate carbon. The

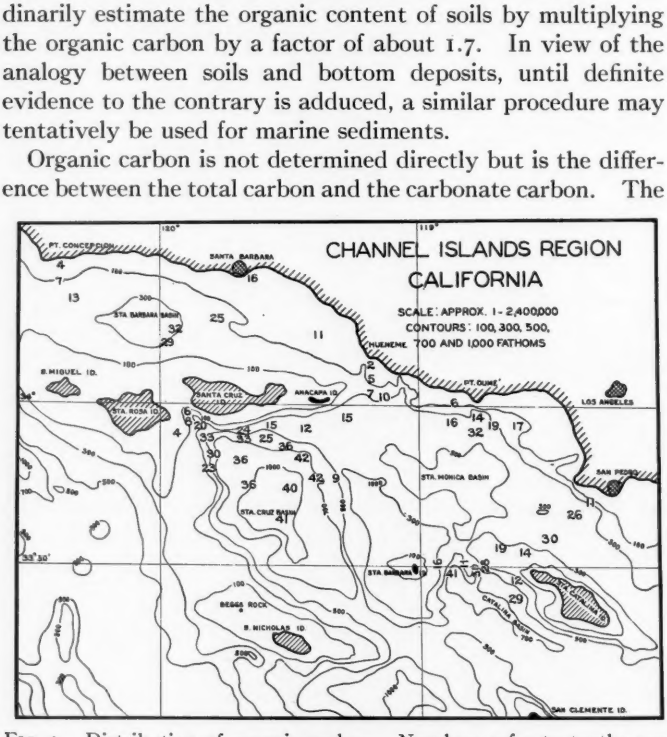

FIG. 4. Distribution of organic carbon. Numbers refer to tenths per cent. of organic carbon.

process of analysis is time-consuming. Furthermore it is difficult to procure satisfactory duplicates. Therefore, as a rule only a few determinations are made; but because of the

importance of the Channel Islands region, organic carbon was ascertained on nearly every sample, and almost all the analyses have been duplicated.

The distribution of organic carbon in the sediments of this region is shown in Fig. 4. The organic carbon content ranges from 0.4 per cent. in a near-shore sand to 4.2 per cent. at the bottom of the Santz Cruz basin. Similar to the texture of the sediments, the organic content follows the bottom configuration. It is high in the depressions and low on the ridges. The dependence of the amount of organic matter upon the submarine topography is well illustrated in the section eastward from Santa Barbara Island. On the slope into the depression the quantity of organic carbon is 1.6 per cent., in the basin it is 4.1 per cent., on the submerged ridge it is 1.1 per cent., in the valley beyond 3.1 per cent., and on the slope out it is 2.8 per cent. Similar variations occur in other parts of the region. The anomalously high content in Santa Barbara Harbor is probably due to sewage.

In some places, the organic matter shows a closer relationship to the depth of water than does the texture of the sediments. The deposits in all the four basins discussed in this paper are similar in mechanical composition, but the amount of organic matter is greater in the deeper basins than in the shallower. In the Santz Cruz and Catalina depressions it rises to over four per cent. compared with about three in the others.

Samples 6 and 652 are of considerable geologic significance. They occur in 420 and 800 fathoms of water, respectively, and both have essentially the same mechanical composition, their medians being 11 and 6.2 microns respectively. However, sample 6 contains only 1.5 per cent. organic carbon compared with 4.2 per cent. in sample 652. Distillation tests indicate that sample 6 is of doubtful potentiality as a source bed of petroleum, but sample 652 is one of the best future potential source beds that has been encountered in this investigation of recent sediments. Thus, within twelve miles a deposit, without altering its physical character to any

appreciable extent, changes from a sediment that is probably a very poor potential source bed of petroleum to one that presumably is very rich.

Variations of this type may have considerable significance for the petroleum geologist, for if they are a characteristic feature of source beds in oil fields, they would have an important effect on the production of petroleum. The writer has already mentioned this in a brief summary of work on this project.[7]

The inference that the shale samples found at stations 665, 666 and 671 are probably Monterey Miocene in age is based on the occurrence of the Monterey formation a short distance away on adjacent islands; the high organic content; and the lithologic resemblance. Samples 665 and 671 contain 5.6 and 4.7 per cent. organic carbon, respectively, which is very high, and compares favorably with assays from the Monterey shale itself.

Ignition Loss.—The loss on ignition is of considerable aid in measuring the organic content of sediments. Although it is only a crude measure, it gives a very rapid means of assaying a series of samples. The organic content can not be any greater than the ignition loss and, except for deposits rich in calcium carbonate, the organic content of the sediments in any individual environment of deposition varies roughly with the ignition loss.

This latter feature is well exemplified by a comparison of Fig. 3, which shows the distribution of organic carbon, with Fig. 5, which gives the ignition loss of the sediments in the Channel Islands region. Except for shell-rich deposits, such as samples 408, 427, and those in the valleys at the northwest end of the Santa Cruz basin, the ignition loss in a general way follows the organic content. It ranges from 2 per cent. in some of the near-shore sands to 17 per cent. in the Santa Cruz basin. Naturally, it does not vary directly with the organic matter, for as the sediments become finer

[7] P. D. Trask, "Origin and Environment of Source Beds; a Summary Report of Progress," *Bull. Amer. Assoc. Petr. Geol.*, vol. 14, pp. 311–314, 1930.

they contain more adsorbed water and hydrous minerals, which cause the ignition loss to increase more rapidly than the organic matter.

The data indicate that any sample in this region that has an ignition loss greater than 12 per cent. and does not contain many shell fragments, in all probability is rich in organic matter. However, even though this relation holds fairly

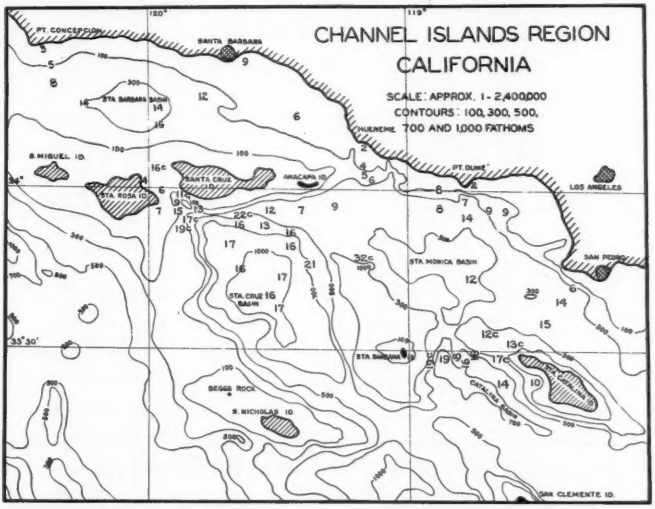

FIG. 5. Variation in ignition loss. Numbers refer to per cent. ignition loss. *C*, samples rich in shells.

well for the Channel Islands district, it does not follow that if in another region a sediment is poor in carbonate and has an ignition loss of 12 per cent., it will be rich in organic matter. It would depend upon the quantity of adsorbed water and hydrous minerals in the sample.

Nitrogen Content.—The distribution of nitrogen in the sediments of the Channel Islands region as shown in Fig. 6 indicates that nitrogen may be used as an index of the organic content. In fact, as nitrogen was determined in every avail-

able sample, Fig. 6 gives the most representative picture of the distribution of organic matter in this environment of deposition. The quantity of nitrogen follows the configuration of the sea bottom as do the other measures of the organic matter. It ranges from .03 per cent. in some of the

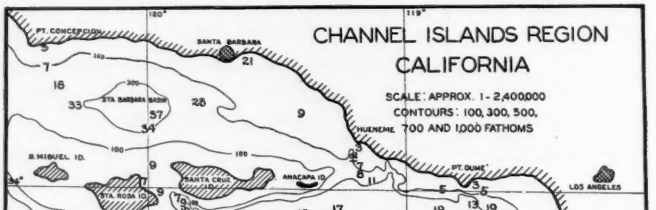

FIG. 6. Distribution of nitrogen. Numbers refer to hundredths per cent. of nitrogen.

near-shore sands to .56 per cent. in the deeps. It follows very closely the irregular submarine topography of the section east of Santa Barbara Island. Even the floor of the narrow valley at Hueneme is richer in nitrogen than the flat-topped banks on either side.

CARBON-NITROGEN RATIO.

The ratio of organic carbon to nitrogen in recent marine sediments is fairly constant. The average for this ratio, based on analyses made by Harald E. Hammar on 25 sediments from 18 representative environments of deposition,

adjacent to the coasts of North and South America is 8.5. The mean for 85 samples from the Channel Islands region is 8.3 and the average for all sediments analyzed is 8.4. Furthermore the ratio is approximately the same for rich and poor deposits, as the mean for samples containing more than 2.8 per cent. organic carbon is 8.5, for those having between 1.4 and 2.8 per cent. carbon is 8.4, and for those with less than 1.4 per cent. carbon, 8.2.

The coefficient of correlation between carbon and nitrogen for the 25 representative sediments from many environments is .942 ± .016 and for the Channel Island deposits, .975 ± .004. This demonstrates a very close relationship between carbon and nitrogen.

The frequency distribution of the ratios approximates the bell-shaped probability curve. One half the ratios lie within 12 per cent. of the mean value of 8.4, 80 per cent. within 25 per cent., and 96 per cent. within 40 per cent. The probable error, as determined respectively by the standard deviation and semi-interquartile range, is 1.12 ± .05 and 1.00. This means that the chances are even that any random determination will differ less than one unit from 8.4, about 4 to 1 that it will differ less than two units, and approximately 20 to 1 that it will differ less than 3 units.

When one considers the difficulty of determining accurately the small quantities of organic carbon and nitrogen in these sediments and the different kinds of organic matter in the various deposits studied, it is remarkable that the carbon-nitrogen ratio of all types of recent marine sediments varies within such close limits.

The relative constancy of the carbon-nitrogen ratio is a valuable adjunct to the study of organic matter in sediments, as it affords another means of determining the organic content of a deposit; for since organic carbon is 8.4 times more plentiful than nitrogen, the organic content may be computed directly from the nitrogen by multiplying by a factor of $8.4 \times 1.7 = 14$. Naturally this ratio of 14 is an approximation. The reliability of the factor of 1.7 for computing organic matter from

organic carbon is not known. Presumably its probable error is of about the same order of magnitude as that of the carbon-nitrogen ratio. Therefore the estimation of organic matter from nitrogen is probably not much less reliable than its determination from organic carbon.

Nitrogen is determined more quickly and more accurately than is organic carbon, and individual analyses have a smaller probable error than do single organic carbon determinations. Consequently, as a routine procedure the estimation of organic matter can be obtained most satisfactorily from nitrogen, although the results should be checked occasionally by organic carbon determinations.

Nitrogen may also be used as a check on the accuracy of individual organic carbon measurements, for if the carbon-nitrogen ratio deviates markedly from 8.4, the chances are favorable that organic carbon has been determined inaccurately.

In carbonate-rich sediments, nitrogen is the best means of determining the organic matter, for in deposits of that type the quantity of carbonate carbon is considerably greater than that of organic carbon, and inaccuracies due to incomplete decomposition of the carbonates have a pronounced affect on the determination of organic carbon, which represents the difference between total carbon and carbonate carbon.

The carbon-nitrogen ratio of sediments of past geologic age is nearly twice as great as that of recent deposits. Insufficient data are at hand to ascertain if it is constant in sediments of this type, but the few determinations that have been made suggest a ratio of about 14, which is nearly double that for fresh sediments. This indicates a loss of nitrogen with respect to carbon during diagenesis. Furthermore the ratio of organic matter to organic carbon in the past deposits must be less than 1.7, because of processes of reduction that occur during burial of sediments. Consequently a different set of factors will be needed for past deposits.

SUMMARY.

The mechanical composition of the deposits of the Channel Islands region varies with the configuration of the ocean bottom. The finer sediments accumulate in the basins and the coarser deposits form on the divides between the basins. Submarine topography influences the nature of the sediments to a greater extent than does depth of water or distance from shore. This apparently is due to its effect on circulation of water, which in turn influences the texture of the sediments accumulating on the sea bottom. The finer deposits of the Pacific Coast region are more coarse-grained than corresponding sediments forming off master streams, such as the Orinoco, Mississippi, or McKenzie. This relative coarseness of the Pacific deposits is correlated with greater relief of the land and the suggestion is made that mechanical analyses of sediments of past geologic age may aid in interpreting the nature of the relief of the regions supplying the debris for the deposits. The calcium carbonate content of the sediments is variable but in general is less in shallow water than in the depressions, where it reaches a maximum of 16 per cent. The organic content varies with the bottom configuration, and ranges from less than 1 per cent. in some near-shore sands to about 7 per cent. in the deposits in the bottom of the Santa Cruz Basin. The ignition loss is a rough index of the amount of organic matter. The carbon-nitrogen ratio of recent deposits does not vary greatly from 8.4. Consequently, the organic content of sediments may be estimated by multiplying the quantity of nitrogen by 14. Sediments of past geologic age contain about half as much nitrogen with respect to carbon as do recent deposits.

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STRUCTURAL GEOLOGY OF THE CONCEPTION BAY REGION, AND OF THE WABANA IRON ORE DEPOSITS OF NEWFOUNDLAND.[1]

ALBERT O. HAYES.

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INTRODUCTION.

THE structural geology of the coast and islands of Conception Bay (Fig. 1) has a bearing on the interpretation of the submarine extent and the recovery of the great iron ore deposits which outcrop only on Great Bell Island.

Except for the glacial deposits, the youngest rocks remaining on the Avalon Peninsula are of Ordovician age; pre-Cambrian rocks are exposed over most of the region. The rocks have suffered repeatedly from compressive earth movements. The region forms part of the great Appalachian mountain system which was modified by at least four epochs of crustal shortening in Paleozoic time, and by folding and block faulting in Mesozoic time. Con-

[1] Presented before The Society of Economic Geologists, Charlottesville meeting, April 25, 1930.

tinued erosion of the surface by streams, ocean waves, and moving ice, has removed all rocks younger than Ordovician which may have existed, and therefore the history of later Paleozoic, Mesozoic, and Cenozoic time has to be inferred from the records of rocks of these ages found elsewhere.

There remain, however, great thicknesses of sedimentary and volcanic rocks that preserve the records of successive earth movements, for all the disturbances of the earth's crust have left their impressions by folds and breaks on these older rocks.

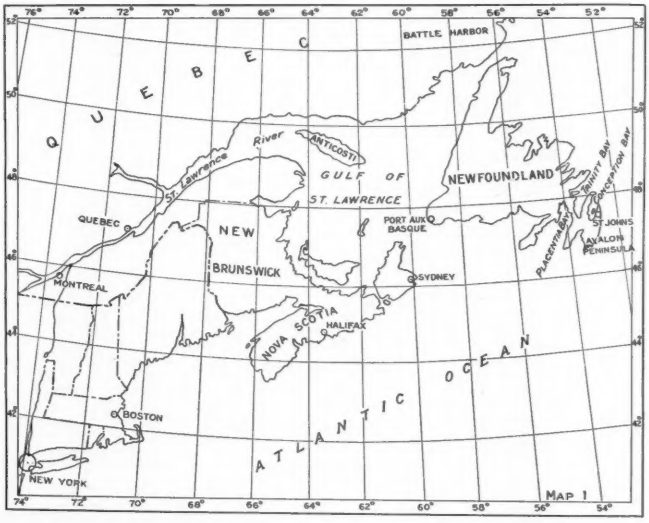

FIG. 1. Index map showing position of Conception Bay, Newfoundland.

The great folded mountain ranges, which in late Paleozoic time were of Andean proportions, were levelled in Mesozoic time and then regionally uplifted and broken to form the flat-topped uplands at present found in Newfoundland.

The relations of the ore beds and the strata of Cambro-Ordovician system in which they occur, to the barren pre-Cambrian formations beneath, are shown in Table I, and their surface and underground distribution are illustrated by Fig. 2.

TABLE I.

TABLE OF FORMATIONS.

Era.	*Period.*		*Rock Series.*	*Thickness.*	*Character.*
	Quaternary		Pleistocene (Glacial)	0–50 ft.	Boulder clay, sand, boulders.
Cenozoic	Tertiary (Absent)				Absent—Represented by erosion and Tertiary earth movements.
Mesozoic	(Absent)				Absent—Represented by erosion and Mesozoic earth movements.
	Ordovician		Wabana and Overlying strata	3000 ±	Pyrite beds, Scotia (Middle) and Upper beds of Iron Ore, Shale and Sandstone.
Paleozoic			Bell Island and Underlying strata	6000 ±	Shale and Sandstone Dominion (Lower) bed at top.
	Cambrian		Upper Cambrian Middle Cambrian Lower Cambrian	1000 ±	Sandstones, Shales, Limestone, and Conglomerate.
		Avalonian Series	Blackhead Signal Hill St. John's Slates (Named also Momable or Aspidella slates)	15000 ±	* Dark gray sandstone and slates. (*g*) Red Conglomerate and sandstone. (*f*) Grayish red sandstone, gray fine grained quartzitic sandstones.
			Torbay		(*e*) Dark greenish gray quartzitic sandstone and slates.
Pre-Cambrian	Keweenawan and older				(*d*) Green and reddish brown and dark gray slates.
			Unconformity Conception slates	10000 ±	(*c*) Flint-like sediments. Dark gray sandstones. Gray purple sediments composed partly of volcanic ashes and coarse fragmental rocks at base.
					(*b*) Complex of green schists with basalt and rhyolite lava flows
			Avondale Volcanics ?		(*a*) and volcanic breccia with basalt and granitic intrusions. Volcanic breccia may be the same as at the base of Conception slates.

* (*a*)-(*g*) are Murray's reference letters.

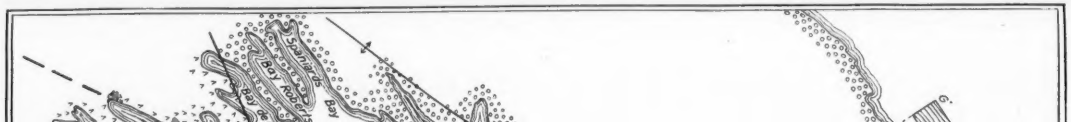

FIG. 4

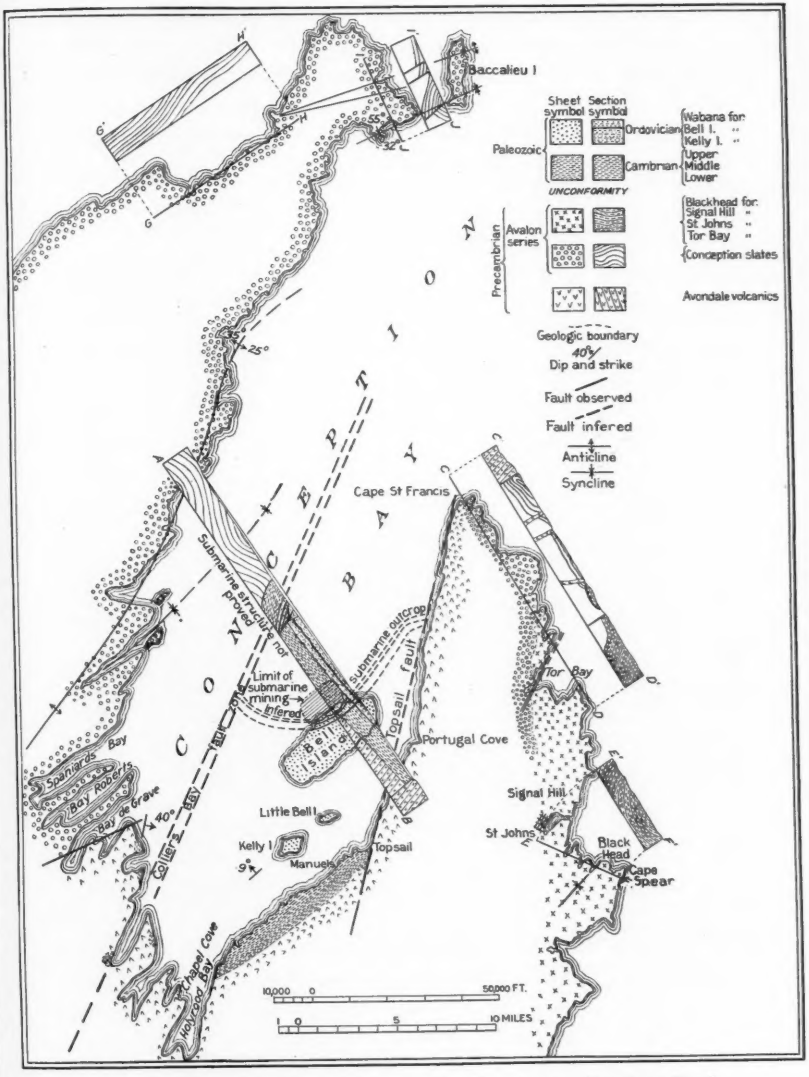

FIG. 2. Structural geology, Conception Bay region, Newfoundland. (Map oriented astronomically, north to top.)

base of Conception slates.

* (a)–(g) are Murray's reference letters.

The ore beds, and also all the accompanying Cambro-Ordovician measures here discussed, are of sedimentary origin. The data supporting this conclusion have previously been published by the writer.[2]

STRATIGRAPHY.

The actual relationships of the rock formations are shown in Fig. 2, and in the superposed vertical structure sections along the lines *AB, CD, EF, GH,* and *IJ.*

The oldest rocks of this pre-Cambrian floor are described by Buddington as the Avondale volcanics, and underlie the Cambro-Ordovician formations unconformably at Manuels River southeast of Bell Island. (*AB,* Fig. 2). The inferred submarine outcrop of the ore beds illustrates the position of the interpreted limit of the ore beds along the Topsail fault against the Avondale volcanics and Conception slates series at Bauline, south of Cape St. Francis, and against the Collier fault zone west of Bell island. The igneous rocks are separated from the Conception slates at Cape St. Francis by an east-west fault as shown in Section *CD,* Fig. 2. The Conception slates exhibit a general northwesterly dip varied by local undulations, and the highest strata are in thrust contact with the Avondale volcanics. The uppermost strata are thick bedded quartzites, which are overturned in a recumbent syncline thrust against a vertical fault. The fissured zone is filled with quartz and marks the break in the direction N. 60° E. at the landing cove east of the Light House, at Capt St. Francis. The lowest beds of the Conception slate formation observed by the writer are water-laid volcanic ashes interbedded with sandstone and slate but only well exposed on the north side of Conception Bay, more particularly along the Trinity Bay shore from Old Perlican to Grate's Cove, and at Bay Verd, Conception Bay (*GH,* Fig. 2).

Alexander Murray[3] (1881) recognized the order of sequence of these pre-Cambrian formations and lettered them *a, b, c, d, e,*

[2] Geol. Surv. Can. Mem. 78, 1915. *Min. and Metall.,* Aug., 1928, pp. 361–366. ECON. GEOL., vol. 24, pp. 687–690, 1929

[3] Murray, A., and Howley, J. P., Geological Survey of Newfoundland. Edward Stanford, London, 1881.

f, g, in ascending order, as shown in his original section (see Table I.).

Professor Buddington gave the name Avondale volcanics to Murray's (a) and (b) formations.[4] As the unconformable relation of the Avondale volcanics to the Conception slates described by Buddington has not been observed by the writer, these two series are considered together. The lowest strata seen in the Conception slate series are volcanic breccias, and the Conception slates are also penetrated by basic and acid intrusives. Consequently there needs to be a most careful study to distinguish between igneous rocks that may antedate and those that may be intrusive into the Conception slates.

Section *CD,* Fig. 2, also shows that the lowest exposed portion of the Conception slates along the coast southeast of Cape St. Francis are brought up in an anticline at Pouch Cove. Continuing southeasterly to Red Head, north of Torbay, the Conception slates occur in flat undulating folds and so extend along about the same horizon with only a few hundred feet of strata exposed. The lower strata of this formation, which are not here exposed, are well displayed at Old Perlican, on the north side of Conception Bay, and it is inferred, therefore, that the Old Perlican volcanic pyroclastic rocks underlie the slates between Cape St. Francis and Red Head. Since volcanic fragmental rocks, however, are usually confined to a limited area in the vicinity of volcanoes, they may be absent in this Cape St. Francis section.

The Conception slates are overlain at Red Head, Torbay, by a basal conglomerate of angular fragments and worn pebbles consisting mostly of the underlying Conception slates and of the intrusive igneous rocks associated with them.

The unconformity separates the Conception slates below from the overlying sediments at Flat Rock Cove, which appear to be the basal conglomerate of the Torbay, St. John's slates and Signal Hill series.

The conglomerate is in faulted contact with the Torbay slates,

[4] Buddington, A. F., The Pre-Cambrian Rocks of Southeast Newfoundland,, *Jour. Geol.,* vol. 27, pp. 449–479, 1919.

and although the sequence is broken, it lies at the base of this uppermost thick series of pre-Cambrian sediments.

The names Torbay Momable (St. John's slates), and Signal Hill were given by Dr. C. D. Walcott [5] to lithologically different members of the series in ascending order and correspond with Murray's *d, e, f, g,* members.

This series is composed of an apparently conformable sequence of strata 15,000 feet thick, more or less, and is best exposed along the coast from Torbay to Cape Spear. The lowest beds may be the coarse red conglomerate, already mentioned, that lies unconformably above the Conception slates at Red Head, north of Torbay, and in the crumpled red and gray slates and sandstones on the east shore of Torbay. This is the Torbay formation. The higher St. John's slates are seen in Middle and Outer Cove and in St. John's City. The green and red sandstones of the Signal Hill formation extend from Logy Cove to Signal Hill, and along the south side of St. John's Harbour, the entrance to the Harbour being cut through them.

The recent critical study of the structural relations of these formations confirms the writer's views regarding the system of thrust faulting, illustrated by Fig. 2, and the overlap of the Cambrian, Bell Island, and Wabana strata on the Avondale volcanics and Conception slates which compose the oldest representatives of the pre-Cambrian formations of the Avalon peninsula.

STRUCTURAL GEOLOGY.

The structure of both the pre-Cambrian and the Cambro-Ordovician of the shores and islands of Conception Bay and of some parts of the coast of Trinity Bay has been again critically examined in order to obtain reliable data on which to base a conception of the position of the ore-bearing rocks that dip to the northwest beneath the sea on the north shore of Great Bell Island, and continue almost unchanged in dip for two miles or more.

Pre-Cambrian.—There have been several periods of earth move-

[5] Walcott, C. D., Pre-Cambrian Fossiliferous Formations, *Geol. Soc. Amer. Bull.* 10, 1899. Random, a Pre-Cambrian Upper Algonkian Terrane, *idem,* 11, 1900.

ment, some taking place before and others after the deposition of the Cambro-Ordovician iron-ore bearing series. Movements that occurred in pre-Cambrian time have not directly affected the ore rocks, but it is probable that they form lines of weakness along which, or parallel to which, dislocations or faults of post-Ordovician time have taken place.

The surface features of the Avalon Peninsula to the west and north of Conception Bay are characterized by a general north-northeast trend (Fig. 2). This topography owes its origin to an important feature of the geological structure, namely, a series of nearly parallel faults that trend approximately north-northeast. The major faults are overthrusts similar to those of Chapel Cove (Fig. 4). Normal faults occur due to gravitational adjustments after the relief of compression.

The deeply indented bays at the head of Conception Bay with their nearly parallel shore lines are considered to be the result of such faults. Lines of hills commonly form the shores of these bays and continue inland as fault scarps or ridges. A series of observations of the strike of the Avalonian rocks and fault scarps that occur from Carbonear to Island Cove on the north shore of Conception Bay, revealed a remarkable parallelism between the strike of the beds, of the scarps, and of the direction of the coast. The general direction of this coast has probably been determined by a major fault or series of faults, and many minor faults have modified the coast line. The peculiar rectangular bays, such as Western Bay and Northern Bay, are examples of such subsidiary dislocations.

There is abundant evidence that the Cambro-Ordovician series originally covered greater area than now, since they occur not only in Conception and Trinity Bays, but are wide-spread over the Avalon Peninsula. Erosion has removed the upper part of the series in Trinity Bay where observations have been made, so that the nature of the ore horizons, if present under the water, is not known. In Conception Bay, unconformably overlying the pre-Cambrian rocks, a thickness of 10,000 feet, more or less, of marine shales and sandstone of Cambro-Ordovician age, accom-

pany the oölite-hematite ores, which outcrop only on Great Bell Island. At the top of 7,000 feet of strata (Fig. 2), the lowest beds exposed are the Lower Cambrian, Middle Cambrian, and Upper Cambrian beds, which are found along Manuels Brook striking N. 82° E., and dipping 10° N. Further up in the series on Little Bell Island, the rocks strike N. 52° E. and dip 9° N. Still higher at the Western limit of the Dominion (Lower) Bed on Great Bell Island, the strata strike N. 65° E. and dip 10° N. The apparent thickness of strata from the basal conglomerate of the Lower Cambrian at Manuels to the ore zone, is about 7,000 feet, making no allowance for dislocations. There is also an unknown thickness, 3,000 feet more or less, above the ore. This series lies on the northern limb of a great anticlinal arch, the axis of which lies in a north-northeast direction on the mainland south of Conception Bay. Along the crest of the anticline all the iron ore and underlying Cambro-Ordovician beds have been entirely removed by erosion, leaving only pre-Cambrian rocks on the St. Johns Peninsula. The basin or syncline covered by the water of Conception Bay is the only part of this great structure in which the ore-bearing strata are known to be still preserved, and the ore beds are exposed to view above sea level only on Bell Island.

The pre-Cambrian rocks exposed along the St. Johns peninsula between Conception Bay and the Atlantic Ocean are complexly folded and broken, having suffered deformation during the pre-Cambrian epochs of severe earth movements as well as by the folding and faulting in Paleozoic and later time, which involved the ore strata.

The basis of observed fact dealing with the position of the iron ore series supposed to be under the water of Conception Bay and in the vicinity of Cape St. Francis and Bauline is as follows: Beginning with the shores of Conception Bay, there is, at Topsail Head, a fault that can be traced about half a mile, showing clearly that the eastern block of which Topsail Head (elevation, 631 feet) forms the southern limit, has been uplifted relative to the bay area to the west. Several hundred feet of the upper beds of the Cambrian slates were cut off by this fault and the remaining beds

were dragged upwards by the movement. As shown in Fig. 2, the direction of this fault is nearly parallel with the coast towards Cape St. Francis. The abruptness of this coast, its almost unbroken scarp face to the northwest, the deep water of the bay close to shore, and the features described at Topsail Head, support the inference that this major fault has formed this headland probably as far as Cape St. Francis. It is interesting to know that Alexander Murray observed this fault and shows it in his sections drawn in 1881. The fault fissure is filled with white vein quartz about 10 feet thick in places.

There are at least three pre-Cambrian epochs of sedimentation accompanied by igneous activity, each terminated by folding, uplifting, and erosion, thus preparing the floor for the accumulation of the Cambro-Ordovician marine deposits which hold the ore. The land was probably raised highest and denuded most deeply at the close of the pre-Cambrian, for there is evidence from the widespread remnants of Cambrian rocks that the sea covered all the Avalon Peninsula except for the higher hills of harder rocks that protruded as islands in a shallow, partly enclosed sea.

Cambro-Ordovician Ore-Bearing Horizon.—The deposition of the great thickness of 10,000 feet or more of sandstone, shale and iron ores in the Cambro-Ordovician gulf was made possible by a progressive subsidence of the sea bottom during the time of their formation. It is likely that down warping occurred along old fault lines of earlier pre-Cambrian epochs of earth movements. Thus, as the load of Cambro-Ordovician sediments increased, and especially as the heavy ferruginous beds accumulated, the great controlling faults bounding Conception Bay from Topsail northwards, and the Colliers Bay faults inferred to extend north-eastward between Bell Island and the north shore, and other lesser breaks, were probably developed. In succeeding epochs, notably at the close of the Ordovician, and when the great Appalachian revolutions closed the Paleozoic era, these initial slips localized the place for great overthrusts such as are shown in the accompanying structure sections and inferred to limit the ore beds.

The Topsail fault may actually be seen as a vertical fissure filled

with quartz at Topsail Head and southwest therefrom, against which the Cambrian strata terminate. The total throw at Topsail Head is not measurable, for it is greater than the 600 feet above sea level elevation of the basement pre-Cambrian rocks in the headland plus the thickness of some hundreds of feet of Cambrian sediments. An upthrust of the east block with a throw of several thousand feet appears probable. The amount of the throw at Bauline is deduced from the fact that the 7,000 feet of strata below the ore appear also to terminate under the sea against the pre-Cambrian fault wall which extends northward along the Conception Bay shore between Topsail and Cape St. Francis (Figs. 2 and 3). The Cambrian ore series has been entirely removed

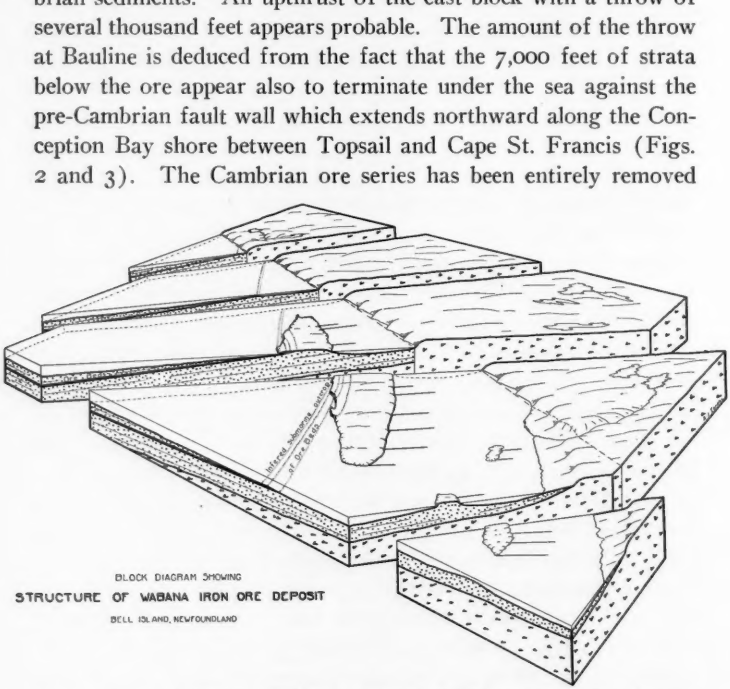

FIG. 3. Block diagram showing structure of Wabana Iron Ore deposit, Bell Island, Newfoundland.

east of the fault and the underlying rocks are 880 feet above sea level at Ore Head, south of Bauline. The Collier Bay fault has also been observed as described, and the method of overthrusting indicated in the accompanying submarine sections of Fig. 2 has been taken from the structural features observed in the lower

Cambrian and pre-Cambrian rocks of Chapel Cove west of Holyrood Bay, as will be later described. Thus the east shore of Conception Bay between Topsail and Cape St. Francis marks the present eastern limit of the Cambro-Ordovician series, but a part of the Cambro-Ordovician series has been cut off and uplifted with the underlying pre-Cambrian rocks and has since been eroded away from the peninsulas both to the east, south and north of Conception Bay.

The structure of the Cambrian rocks at Brigus and other outliers of Cambrian at the head of Conception Bay also has a bearing on this problem inasmuch as they indicate the northern workable limit of the present Submarine Mines, and is referred to later.

Cambrian rocks are found at various points on the shores and islands of Trinity Bay, and observations were made at Heart's Desire, Heart's Delight, Spread Eagle Bay, Norman Cove and Smith Sound. The attitude of the series shows a continuing sequence of the nearly parallel anticlines and synclines whose axes strike north-northeast approximately, giving further proof that the governing compressive forces are the rule in this region. At Heart's Desire a spooning synclinal occurs, the axis of which pitches gently to the south-southwest. The beds of the north limb at a distance of about 1,000 feet southwest of the nose of the synclinal have a strike N. 55° E. and dip 26° SE. The red rocks at Island Cove, which strike N. 13° E. and dip 51° W., probably form a portion of the south limb of this synclinal. At Spread Eagle Bay these rocks continue to dip westwards, whereas at Norman Cove on the point between Long Harbour and Chapel Bay they dip to the eastward, thus forming a synclinal fold between these two points. The next anticlinal arch succeeding to the north is clearly seen at Norman Cove with an axis striking N. 38° E. and pitching gently to the east. Some similar observations were made by J. B. Jukes.[6] On page 73 he writes: "Between Heart's Desire and Dildo Harbour the variegated slate rocks, exhibiting

[6] Gen. Rept. of the Geol. Survey of Newfoundland for the years 1839–40. John Murray, London.

a frequent alternation between greenish-gray and bright red colors, are traversed by several anticlinal lines, running in a direction as nearly as possible north-northeast and south-southwest."

On the west end of Random Island, on the northern shore of Trinity Bay, a thick series of shales and sandstones occurs which from palaeontological evidence appears to be the equivalent of that part of Conception Bay section lying between Manuels Brook and Kelly Island, thus nearly approaching the ore horizons. These Random Island beds have been greatly disturbed but maintain the general strike of N. 20° E. to N. 40° E. and dip steeply to the northwest. They are probably a remnant of a fold, the direction of the axis of which is parallel to the general north-northeast direction of the folds already described. These folds are further indicative of compressional movement in the earth's crust and demonstrate the adaptation of the beds to a more limited lateral area in consequence of compression in a west-northwest direction. The ore horizons appear to have been upfaulted and entirely lost by erosion in this place, but the sequence of strata is the same as in Conception Bay and indicates the probable original spread of the iron ores of these outlying areas, all of which should be thoroughly examined.

Basal Cambrian Rocks as Indicators of the Cambrian Sea-Bottom.—While 18 feet of coarse conglomerates followed by 30 feet of limestone and shales were being deposited near the Cambrian shore line at Manuels, 2 to 5 feet of fine grained grit conglomerate followed by 470 feet of limestones and shales were contemporaneously formed at Brigus Head with an intermediate thickness at Chapel Cove. The basal beds of Trinity Bay have also a development comparable to that found at the head of Conception Bay. This phenomenon indicates that the Cambrian sea was deeper to the westward and northward from Manuels. That the Cambrian sea covered much of that which is now land is evident from the occurrence of small folded areas of lower Cambrian sediments which lie on the tops of the pre-Cambrian peninsulas. It is probable that the greater part of the Avalon Peninsula was so covered.

Structural History.

After the deposition of the thick Cambro-Ordovician sediments containing the iron ore beds, a period of major earth movements took place during which the bedded ore-bearing rocks were compressed into folds. A synclinal trough occupied the area now marked by Conception Bay and a succeeding anticlinal arch occupied the peninsula between Conception and Trinity Bays. A series of minor folds followed on the south coast of Trinity Bay, with others of greater magnitude as shown at Chapel Arm and on Random Island.

Structure of the Cambro-Ordovician Ore-Bearing Series of Conception Bay.—Combined with the folding movements described above, major faulting occurred, and the field evidence shows that the majority of these breaks are due to thrusts. The fault at Topsail Head has already been referred to. It has a direction of N. 11° E. as compared with a general strike of the ore beds of N. 52° E. The eastern coast of Conception Bay to Topsail Head has been uplifted and although the actual amount of uplift has not yet been ascertained, it appears to total at least the elevation of the pre-Cambrian coastal hills above sea level, which is about 880 feet at Ore Head plus the 7,000 feet thickness of the Cambro-Ordovician series below the ore (Fig. 3).

Many faults have been found on Great Bell Island and they exhibit a variety of strikes and dips. There is, however, a marked parallelism in the direction of two sets of these faults, one striking about N. 25° E. the other about N. 67° W.

At Brigus Head, the Cambrian rocks have been intensely folded and faulted. The axis of the folds and the directions of the faults strike about N. 15° to 20° E.

Thus, there is ample evidence to prove that the region as a whole is characterized by great dislocations due to compression. This strengthens the view that the ore beds and the nearly two miles thickness of sediments accompanying and underlying them, proved to have a uniform strike on Kelly, Little Bell and Bell Islands and a nearly uniform low dip, must be cut off towards Bauline in a similar manner as observed at Topsail and that the

ore lies against the Topsail fault in the vicinity of Bauline. (Figs. 2 and 3.)

Structure of the Cambrian Rocks of Chapel Cove.—North of Chapel Cove on the peninsula between Holyrood Bay and Harbour Main, the Lower Cambrian rocks extend for about half a mile along the eastern shore. The structural features exhibited here were studied and mapped in detail by the late Professor Gilbert van Ingen of Princeton University and are thought to demonstrate in a restricted zone, the tectonics of Conception Bay as a whole. They are shown in Fig. 4.

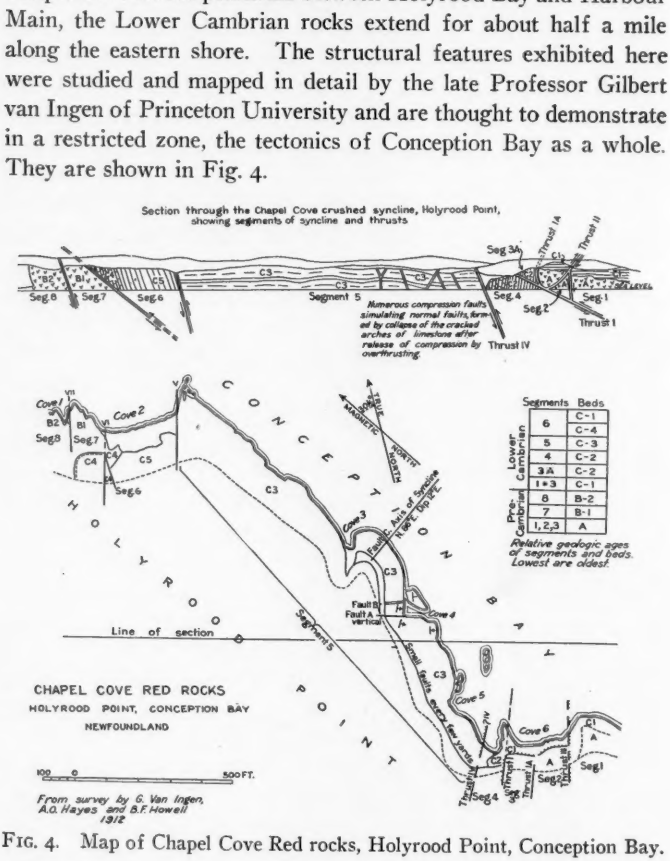

FIG. 4. Map of Chapel Cove Red rocks, Holyrood Point, Conception Bay.

At the south and north ends of the Cambrian limestones and shales, pre-Cambrian rocks are found. A zone of thrusting occurs also at each extremity, the thrusts having a general north-

northeast direction. These thrusts have cut the Cambrian series into segments: the pre-Cambrian segment 1, followed by four small segments, numbers 2, 3, 3a, and 4, are found at the southeast end, then a long segment, number 5, followed by two narrow segments, numbers 6 and 7, of which number 6 is Cambrian and number 7 is pre-Cambrian, and finally the pre-Cambrian of segment number 8 at the northwest end. Each segment has been shoved from the southeast and pushed towards the northwest over upon its neighbor on that side. The pre-Cambrian to the south has been upthrust and has overridden the Cambrian, forming a crushed zone between the pre-Cambrian and the less disturbed middle segment 5. The northern boundary of segment 5 is marked by a thrust and the beds beyond have been overridden to such an extent that all of the visible strata of segment 6 are stratigraphically higher than those of segment 5. Segment 6, containing the highest beds in the section, is in its turn thrust over the pre-Cambrian segment 7 to the north and this again is thrust over the most northerly portion of the section.

This section shows a synclinal trough of Lower Cambrian beds broken by thrusts, with the complementary anticlines inclosing cores of pre-Cambrian rocks, elevated to levels far higher than those of the Cambrian beds.

This type of structure appears to offer a key to the interpretation of the larger features controlling the deformation of the stratified rocks, including the ore-bearing series of the whole of Conception Bay; it seems to portray in more compact form the nature of the movements that have operated in perhaps larger and more widespread fashion over the entire region of the Conception synclinal.

This principle applied to the rocks underlying Conception Bay is illustrated by *AB*, Fig. 2, taken from Topsail Head to Spout Cove, 5 miles northeast of Carbonear, and portrays the probable larger structural features that may be met in the continuation of the submarine workings that develop the ore zone. It should be stated that the submarine structure including the great thrusts and the attitudes of the ore zone indicated in the Collier fault zone of this section, are purely hypothetical, although based upon the ob-

servation of prominent structure lines with thrust faults and scarps found on the north and west shores of Conception Bay, as has been previously indicated.

LIMITS OF THE IRON ORE.

It is impossible to examine the submarine portions of the ore beds beyond the reach of exploratory drills projected from the shores or mine workings, to prove the presence of such great thrust faults as shown in the theoretical sections, but the basal Cambrian beds at Brigus give a clue to the attitude of the north limb of the Conception Bay syncline. These beds dip at steep angles to the east, and are broken and crushed as shown by the isolated southwesterly syncline at the west end of Colliers Bay and the Bacon Cove outlier in the east shore of Colliery point, confirming the evidence from Chapel Cove.

Professor Buddington described the faulting as follows:[7]

> These faults trend in the main little east of north, and the throw along many of them is measurable in thousands of feet. A few of the more important ones are the fault between the Cambrian and the pre-Cambrian along the east side of Conception Bay from Topsail to Cape St. Francis, with a throw of 8,000 feet, as determined by Van Ingen; the fault a short distance inland from the west side of Colliers Bay in Conception Bay, which may be traced for almost ten miles and separates the Cambrian from the pre-Cambrian and the Conception slates from the volcanic series, and lastly the fault on the west side of Random Sound, which may be traced for fifteen miles and brings Cambrian beds against pre-Cambrian granite and the Conception slate series.

From the foregoing argument regarding the great over-thrusting along both the east and west coast of Conception Bay, it follows that the limits of the ore from Bauline to Cape St. Francis are probably fixed by faults, and it is also to be expected that the northern limits of the ore are along the fault line from Colliers Bay to the middle of Conception Bay about half way between Cape St. Francis and Broad Cove Head, or some six miles from the outcrop.

[7] *Op. cit.*

DISCUSSION OF PREVIOUS WORK.

Although there is general agreement regarding the presence of such great faults, a decided difference of opinion has been expressed recently as to the nature of the folding in the vicinity of Saint John's, and as to the presence of important faults along the east coast of Conception Bay. As the submarine extent of the Wabana iron ores must be considered in accordance with whatever view is accepted of the structural relations, considerable importtance attaches to the proper interpretation of the nature of the folds and faults in the region from St. John's to Cape St. Francis and the coast and islands of Conception Bay.

In the report by Dr. Herbert A. Baker,[8] the geology of the pre-Cambrian rocks of Newfoundland is reviewed and the idea is expressed that the succession between Cape Spear and Conception Bay may have been wrongly interpreted by J. B. Jukes,[9] and the former Newfoundland government geologists, Alexander Murray [10] and James Howley.[11] Dr. Baker states (p. 22): "In spite of the fact that Murray's grouping of the pre-Cambrian rocks has stood unchallenged since 1868, I know of no sections which show conclusively that his '*c*,' '*d*,' '*e*,' and '*f*' beds are older than the Signal Hill Conglomerate, as he stated." Also on page 24: "Again, assuming Murray's order of succession to be correct, how is the juxtaposition of the *oldest* pre-Cambrian, instead of the *youngest*, with the basal beds of the Cambrian, in the Conception Bay area, to be accounted for? Only by assuming the existence of an enormous unconformity (unproved) or a gigantic fault, with a throw of thousands of feet, which has dropped the Cambrian and Ordovician against the older rocks, (an assumption also unproved and a drastic one to resort to without adequate evidence)."

In addition Dr. Baker states [12] that it is not necessary to explain

[8] General Report of the Government Geologist for 1928, pp. 17–27, St. John's, Newfoundland.

[9] *Op. cit.*

[10] *Op. cit.*

[11] Geological maps of Newfoundland, 1907.

[12] *Daily News*, Saint John's, Newfoundland, December 31, 1928, p. 41.

the geological relations between the Paleozoic and pre-Cambrian rocks by a fault, but he states that in his examination of the pre-Cambrian rocks around Conception Bay he thinks he has made a great discovery, which he describes as follows:

> The discovery that I think I have made is that the pre-Cambrian rocks of the Peninsula of Avalon are affected by a grand isoclinal fold, which can be traced for 60 miles and appears to be about six miles in width. As a consequence it appears necessary that the previously accepted order of sequence of the pre-Cambrian strata must be modified.

After reviewing the early geological work in Newfoundland, Dr. Baker continues:

> Not until now has any question ever been raised as to the correctness of the early reports on the pre-Cambrian rocks of this country. On the previously accepted conception of the structure of the strata, older and older beds were expected to be encountered, as one proceeded from St. John's towards Conception Bay. But on arriving at Conception Bay one finds first Cambrian, and naturally one would think they would lie on the top of the top of the pre-Cambrian. These are followed in Bell Island by Ordovician rocks containing the famous Wabana Iron Ore Mine. The difficulty has been in the past to account for the fact that Cambrian and Ordovician rocks were met with adjacent to what were supposed to be not the highest but the lowest beds of the pre-Cambrian sequence. The explanation put forward was that there must be a gigantic fault passing through Topsail and running parallel with the southern shore of Conception Bay. I have many times visited that locality and I am unable to detect any evidences of the existence of this alleged fault. On the other hand if the isoclinal fold which I think I have discovered is recognized, there is no need to "invent" a Topsail fault, as everything then is as it should be.

The writer has found that the Cambro-Ordovician series, in the upper part of which the Wabana iron ores occur, and which is approximately 10,000 feet thick, rests unconformably upon the greatly eroded surface of the pre-Cambrian rocks and the actual contacts have been studied at a number of localities. Not only is there a great unconformity, but there is a great fault which may be seen at Topsail and which is illustrated in Figs. 2 and 3. The writer has found no field evidence to support the theory of the isoclinal fold which Dr. Baker describes, but as is shown below

there is positive evidence to disprove it. The Topsail fault is a proved major feature, and special reference is here made to the matter because of the bearing of the structure which Dr. Baker surmises to be present on the submarine extent of the iron ores in Conception Bay. If his theory were accepted, the writer's interpretation of the submarine limits of the iron ore would have to be modified.

The principal point of difference lies in Dr. Baker's conclusion that there is an anticline in the Signal Hill formation, the axis of which lies parallel to the sea coast just outside St. John's Harbour, and extends for sixty miles to Bay Verd and beyond. Such a fold would cause the higher strata preserved in the Cape Spear syncline (*EF*, Fig. 2) to be repeated with their tops facing west under St. John's city. Thus, Dr. Baker concludes that westward from St. John's to Conception Bay progressively higher strata are crossed and that the iron ore-bearing beds of Bell Island lie unfaulted upon the youngest and uppermost of the pre-Cambrian formations.

Dr. Baker's view opposes that held by all geologists who have studied the region, including J. B. Jukes, 1842; Alexander Murray, 1868; James P. Howley, 1910; Gilbert van Ingen, 1914; A. O. Hayes, 1915; and A. F. Buddington, 1916.

The structure indicated on Fig. 2 is drawn from observations made by the writer in 1911–12, 1927, and 1929. Coarsely cross-bedded grits at Signal Hill, St. John's Harbour, prove the top of the beds to be to the east. Many confirmations of this attitude by eastward facing truncations, and the preservation of the west or underlying portions of the beds, are well exposed along the glaciated surfaces of these strata. Similarly, in Outer Cove, between Torbay point and Torbay, the finer grained cross-bedded sandstones exhibit truncations that prove the top of these strata to be towards the east. Thus the Torbay strata are below the Signal Hill section, and although a fault in Torbay breaks the series, it is natural to infer that the conglomerates at Flat rock and Red Head are the basal members of the series, as indicated by *CD*, Fig. 2.

It should be noted that instead of an isoclinally folded anticline at Bay Verd, there is a broken syncline, the axis of which is in east-northeast direction, and it is quite impossible that an isoclinally folded anticline extends northerly from Cape Spear through Bay Verd and continues for sixty miles along this east coast of Newfoundland.

IRON ORE RESERVES.

Twenty-seven million tons of ore have been shipped since the beginning of operations in 1895. This recovery has proved an average total iron ore content underlying one square mile of surface area of approximately 35,000,000 tons in the present mines, of which about one-half is left as pillars in the submarine mines, giving an average of 18,000,000 tons recoverable ore. The total area and recoverable reserves cannot be proved in advance of mining, but the geological data suggest that the deposits within limits of submarine mining may underlie an area of 70 square miles, more or less, and if the average amount of ore found in the present mines extends over this area, the figure obtained for the reserve is about 2,500,000,000 tons, of which one-half is recoverable by present mining methods.

Much higher estimates have been made,[18] varying from 3,500,000,000 to 10,000,000,000 tons, and while it is impossible to predict the variations in the thicknesses of sedimentary beds of ore over the extensive unproved portions of the promising submarine area, a very large reserve is indicated.

It would, therefore, appear that mining operations may continue on a scale limited only by the amount the market will absorb and the engineering difficulties of submarine operations. The present rate of production of 1,500,000 tons per year probably will be increased considerably in the near future.

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[18] *Trans. A. I. M. E.*, Iron and Steel Division, 1929, pp. 18 and 38.

SUBTERRANEAN WATER CONDITIONS IN THE COASTAL REGIONS OF THE NETHERLANDS.[1]

J. VERSLUYS.

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INTRODUCTION.

THE purpose of this paper is to make my theory concerning the subterranean water of the coastal regions of the Netherlands better known to a wider circle. This theory has already been published in part in Dutch in a series of treatises and official reports which appeared in the years 1918 to 1920. During these years I was the chief hydrologist to the Government Office for drinking water at the Hague, and was entrusted with the conduct of the investigations of subterranean water which were carried out on a large scale on behalf of the Government.

In the following pages a representation will be given of the manner in which salt water and fresh water occur in the Province of North Holland and the Holocene districts to the east thereof, including the Zuider Zee; also the creation of the present subterranean water conditions. Complete lists of the literature respecting the subterranean water of the Netherlands down to the year 1919 have been published by me in collaboration with Dr. J. F. Steenhuis.[2]

[1] Presented before the Society of Economic Geologists in December, 1927; publication has been delayed because of difficulties encountered in preparing the manuscript for printing.

[2] J. Versluys and J. F. Steenhuis: "Hydrologische Bibliographie van Nederland," I., 1915; II., 1917; III., 1919. Amsterdam.

GEOLOGIC HISTORY OF THE AREA.

The history of the Province of North Holland and the Holocene districts to the east, including the Zuider Zee, may be given broadly as follows: After the deposit of the Tertiary, the latest strata of which range from sea to river deposits, the district lay above sea level. For a considerable time sediments brought down by the rivers were deposited, and then began the fluvial Pleistocene. During that time the soil was exposed only to the effects of moisture precipitated from the atmosphere and river water, and must have been penetrated to a great depth by fresh water. The sea, however, was comparatively near. In borings in the fluvial Pleistocene on the Isle of Texel, sea shells were found.[3] Hence the fluvial Pleistocene is regarded as a delta deposit rather than a river deposit. Later, a part of the district was covered by land ice. Even then, however, the ground was exposed only to the effects of fresh water; namely, precipitation and water from melting ice.

After this the ground sank and the sea inundated a part of the territory. At least two inundations took place. The first was that of the Eem Zee, and did not inundate the whole district. At that time the ground was exposed to sea water, much of which must have penetrated into the flooded area. The district of the Eem Zee was afterwards raised above sea level and again received river deposits. The deposits made up to this time are considered to be of Pleistocene age. Later the ground again sank and the Holocene sea covered a great part of the country; that sea inundated the western part of the present Netherlands. There arose afterwards a series of sandbanks with dunes which shut off a part of the sea, forming a "haf" or inland sea. E. Dubois and P. Tesch believe that the sandbanks were formed after the Straits of Dover came into existence; hence estimates concerning the age of the dunes vary from 3,000 to 8,000 years.

To a great degree the haf silted up. As the water became

[3] J. F. Steenhuis: "Beschouwingen over en in verband met de daling van den bodem van Nederland." Mededeelingen omtrent de geologie van Nederland, verzameld door de Commissie voor het geologisch onderzoek No. 40, bl. 39. *Verh. der K. A. v. Wet. te Amsterdam*, Tweede Sectie, Deel XIX, No. 2, Februari, 1917.

shallower and more land was formed, less sea water penetrated through from the tides; that which remained, owning to the supply of river water, became brackish, and in the end nearly or altogether fresh; the Holocene sea deposits and brackish deposits settled upon the Pleistocene deposits. (See Fig. 1, I. and II.)

The haf had for the greater part become silted up and grown

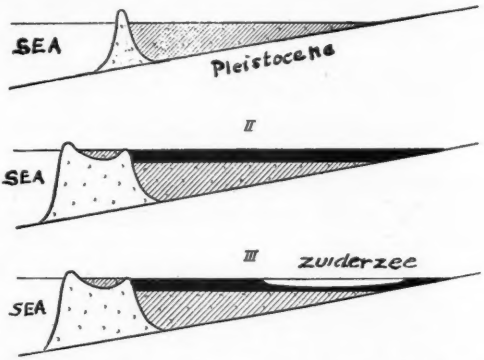

FIG. 1. Diagrammatic geologic cross-section of area described. Stippled area is sea and dune sand; shaded, brackish water deposits; black, fresh water deposits.

over; the sinking of the soil did not immediately stop. However, the sea did not again cover the Holocene strata and the abutting Pleistocene districts. Peat and other fresh water deposits were formed, and as a consequence the condition shown in Fig. 1, II., was brought about.

Afterwards still smaller incursions of the sea, of another nature than the inundations referred to, took place. The sea then washed away great areas of the peatlands, and in this manner the Zuider Zee was formed. (See Fig. 1, III.)

What I have said gives only a somewhat sketchy representation of the history of the formations. Locally the increase and decrease of land has been more in the nature of an exchange.

CHARACTER OF DEPOSITS AND THEIR INFLUENCE ON GROUND WATER.

The subsoil of the dunes consists for the most part of sand, but in the haf the deposits are largely clay. The fresh water deposits in the previous haf are mainly peat. Clay and peat allow of only slight penetration; the Holocene sand deposits are much more permeable. Hence, where the dunes have not been removed by the action of the winds, the formation is more permeable than elsewhere. On the whole, the sand of the Pleistocene is coarser than that of the Holocene and therefore allows the water to percolate more readily.

It is of interest to ascertain how the subterranean water condition of the soil must have become changed by the several geological transitions. In this, one must keep in view the fact that Pleistocene strata on the whole are quite permeable and that the Holocene are not.

In the first marine inundations, presumably, the sea water penetrated very easily into the soil. In the later inundations from the Zuider Zee, generally speaking, only the upper part of the Holocene soil was washed away. In the main, the Pleistocene below the Zuider Zee still remained covered by the lower Holocene strata that were only slightly permeable. Only in the north part of the Zuider Zee, where, owing to the tidal currents, deep channels were cut, were the Pleistocene deposits again exposed in many places and brought into direct contact with the sea water. (See Figs. 2–6.)

CONDITIONS NEAR HAARLEM, AMSTERDAM, UTRECHT, AND THE HAGUE.

As a comparatively simple example, I may first discuss briefly the district lying between Haarlem, Amsterdam, Utrecht and the Hague and the dunes to the west thereof. The later incursion of the Zuider Zee did not extend over this, hence we deal here only with a marine inundation and afterwards the formation and silting up of a haf.

The present condition of this district is known from data ob-

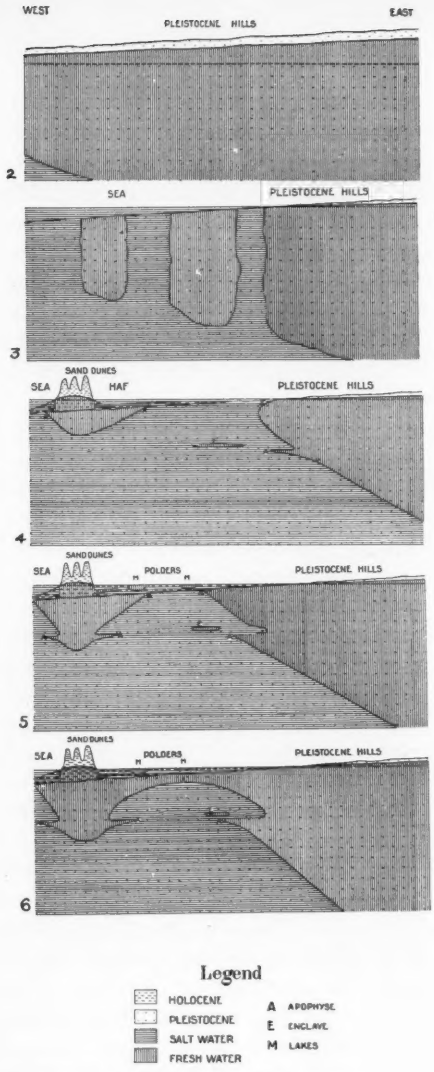

FIG. 2. First stage of penetration of salt water.

FIG. 3. Second stage of penetration of salt water.

FIG. 4. Penetration of salt water finished, first stage of penetration of fresh water.

FIG. 5. Second stage of penetration of fresh water.

FIG. 6. Present condition of fresh and salt water.

tained from many borings, as shown in Fig. 6. The Holocene strata are indicated by lines, the Pleistocene by dots. The horizontal lines show the salt water, the vertical the fresh.

In the dunes at a slight depth the water is fresh, at greater depths it is salt. In the polderland [4] behind the dunes, generally speaking, the water in the most recent Holocene strata is brackish or salt. In the highest parts of the Pleistocene strata, lying below, the water is fresh, while below this again, in the deeper part of the Pleistocene, the water is again salt. I repeat that this is a sketchy representation. Later on I shall discuss the deviations from this representation.

The condition shown by Fig. 6 represents what I have said. Fig. 5 gives another representation. There, as also in parts of the polderland, far from the dunes and the Pleistocene heights, no fresh water is to be found in the Pleistocene strata. Though the water in the upper part of the Pleistocene is not everywhere entirely fresh, it is less salt than at greater depths.

Viewed from a historical point of view, Fig. 6 is the most accurate. There is thus a great difference between the condition of the dunes and that of the polderland. In the dunes the water in the upper strata is fresh, whereas in the polderland, above the fresh water, in the most recent strata there is still salt or brackish water. That difference must be explained thus: the fresh water of the dunes has penetrated to the bottom, while the fresh water below the polders has flowed through the ground from elsewhere.

Various opinions have been expressed concerning the origin of the fresh water as well as that of the salt water in the ground. The most obvious is to assume that the salt water in the ground originates from the sea. This is according to my view.

It has also been held that the salt of the subterranean water might have originated from rock salt deposits. Had this been so, one might expect very weak and also very strong solutions of salt. Solutions containing more salt than sea water have not been met with in the west of the country. Proportions of

[4] "In the Netherlands the term 'polder' is applied to a tract of marshy land lower than the sea which has been diked and reclaimed to cultivation."—Standard Dictionary. (Editor.)

salt, however, have been found which approximate to that of sea water. The fact that the proportion of salt does approach that of the sea, but does not exceed it, makes it probable that the subterranean water is sea water, more or less diluted. I do not know of any evidence that would indicate rock salt as the source of the salt in the subterranean water.

There is another point with which one must be careful when judging of the origin of subterranean water. Upon superficial consideration, one would be inclined to think that if the salt water came from sea water, it would contain, except for the dilution, the same component parts as sea water. That is not so. Many chemical and physical changes have taken place in the ground. Owing to these some of the component parts of the sea water may disappear or they may be exchanged for component parts of the soil. Matter from the ground is also dissolved and the origin of the salt contained in subterranean water does not therefore appear from a chemical analysis. The composition of the subterranean salt water also deviates, here and there, from that of sea water.

There is one important component part of the salts contained in sea water which undergoes practically no insoluble combinations in the ground, that is, the chlorine. In the ground there are no minerals containing any considerable quantity of chlorine. Hence the ground cannot supply chlorine to the water. The proportion of chlorine of the water thus gives a measure of the dilution which the sea water has undergone. Where I spoke of the proportion of salt, I ought really to have spoken of the proportion of chlorine. Practically, however, this amounts to the same.

Below the polderlands and the dunes, at a depth, generally speaking, of not more than 20 meters below the level of Amsterdam, Pleistocene strata are found which in the Gooi and the Utrecht hills rise far above that level (Fig. 6).

The Pleistocene rests upon the Tertiary formation, which is not shown in the plate. The Pleistocene is, for the greater part, a river deposit (formerly called gravel diluvium). During the process of the formation of this Pleistocene river deposit, the district was thus lying above sea level, and upon this sand and

gravel from the river was deposited. A part of the district was still covered by glaciers. From the beginning to the end of the depositing of Pleistocene, by rivers and glaciers, however, the district was land, and was exposed to the water precipitated from the atmosphere. Thus the ground was for long saturated with fresh water precipitated in this manner and from the thawing of the glaciers. That the sea was comparatively near during the formation of the Pleistocene, is proven from the occurrence of seashells in the Pleistocene of Texel, already mentioned. No doubt the sea penetrated thus far.

Deposits by the rivers ceased when, on two occasions, a great part of the district was inundated by the sea. The first incursion of the sea brought the strata of the Eem system; this is still reckoned among the Pleistocene deposits. The later Holocene sea covered the district of the present-day dunes and a great part of the polderland. Before the incursion of the sea, the situation was as shown in Fig. 2. After the sinking the condition arose that is represented in Fig. 3. The Pleistocene strata still contained fresh water; the heavier sea water, however, forced its way through and pushed the fresh water upwards. Once the sea water had penetrated, it was able to force its way further, with continually increasing rapidity. Hence columns of salt water must have temporarily sunk into the ground; however, owing to the clay strata and masses, these columns must have acquired considerable deviations. These details are not shown in figures. I have considered that, respecting this, I must content myself with a very sketchy representation.

The penetration of salt water took place with a certain admixture. The subterranean water, where sea water had penetrated, was therefore not immediately so salt as sea water. In the clay strata, where the movement of water is extremely slow, the driving away of the fresh water would be effected very slowly. At great depth, the fresh water also extended inland, as shown in Fig. 3. Considering that during the condition represented in Fig. 2, the sea was not very far away, some salt water might even then have been in the lower depths.

As has already been said, at least two incursions of the sea

took place. Between those two inundation periods, the land again rose above the level of the sea and there must again have been a penetration of fresh water.

After the termination of the two incursions of the sea, presumably the fresh water was almost entirely driven out from the inundated area, so that the condition shown in Fig. 4 arose. It is quite possible that in some clay strata, especially those situated more to the east, some fresh water still remained, because the forcing out takes place very gradually. A fresh water enclave is shown in Figs. 4, 5 and 6 (see *E*). The inundation by the sea presumably took place slowly, by a gradual decline of the land or by a washing away of the land. The sea came from the west and the western part of the district was thus covered, for a longer period than the eastern part.

It seems to be probable that under the present dunes, before these arose, the penetration of sea water had gone so far that the clay strata, even those of great thickness, already contained salt water. In the neighborhood of the Amsterdam Municipal Water Works these clay strata do contain water that is strongly impregnated with salt, though for a very long time past they have been surrounded by the fresh water which penetrated later. Hence, especially below the present dunes and the western part of the present polderland, since the second inundation by the sea, the fresh water in the ground has been practically driven out by salt water. More to the east the driving out of the fresh water was probably less complete, presumably because the inundation by the sea began later and hence lasted a shorter period.

When the dunes were formed, owing to which fresh water penetrated into the ground, the situation must have been as represented in Fig. 4. The clay strata and some well inclosed masses of sand could still contain fresh water, as is shown by Fig. 4, *E*. In this manner the retention of fresh water enclaves is not out of the question.

Meanwhile, a whole series of dunes were formed and that part of the sea lying behind these became changed into a haf that gradually silted up. As soon as sand banks, upon which the commencement of the formation of the dunes took place, became

raised above sea level, the penetration of sea water ceased. Instead of this, fresh water, coming from precipitations from the atmosphere, penetrated into the ground. It should be kept well in mind that this penetration only took place where the dune formation was oldest. The representation that a great chain of dunes arose suddenly upon a subsoil saturated with sea water is not correct. The penetration of fresh water begins as soon as there is a small series of dunes. The depth to which the fresh water in the subsoil of the dunes penetrates, depends, *inter alia,* upon the age of the dunes.

The penetration of fresh water takes place in an entirely different manner from that of the earlier penetration of salt water. The quantity of water from precipitation from the atmosphere that is able to penetrate is limited. The penetrating fresh water thus has only a limited inlet, while with an inundation from the sea, a practically unlimited quantity of sea water is able to flow in. The salt water is the heavier and has an inclination to sink into the depth (Fig. 3). In corresponding manner the fresh water tends to rise.[5] Thus the salt water accumulated, on incursions of the sea, in the deepest strata, and from there was also able to extend further inland in a horizontal direction (Fig. 3). The fresh water accumulates in the uppermost strata and, in order to penetrate deeper, it also requires a certain pressure head. It endeavors to extend horizontally. This occurs quickest in the coarsest strata. Where the fresh water comes into contact with a sand stratum, it will thus flow off quickest horizontally.

The Holocene strata, on the whole, are less permeable than the Pleistocene. Thus, in the Pleistocene strata the water will flow off horizontally and, owing to its inclination to force its way upwards, remains immediately below the Holocene strata.[6] In the same manner it flows off under the clay strata which are in

[5] See W. Badon Ghyben: "Nota in verband met de voorgenomen putboring nabij Amsterdam," *Tijdschrift van het Kon. Instituut van Ingenieurs,* Verband 1888–1889, p. 21.

[6] C. P. E. Ribbins: "De duinwatertheorieën in verband met de verdeeling van het zoete en zoute water in den ondergrond der zeeduinen, *De Ingenieur,* XIX., No. 4, p. 73, 1904.

the Pleistocene (Fig. 5). The fresh water thus sends out forerunners, through the coarser strata, which I spoke of in 1915[7] as being " fresh water apophyses."

In the meantime the haf, or inland sea, behind the dunes became more and more shut off from the North Sea as the dunes closed up and the haf began to silt up. The rivers having estuaries in the haf brought down much fresh water. The tides, just as at present in the Zuider Zee, brought much salt water in, but, as the entrances became narrower and the enclave shallower, this supply of salt water diminished. The haf therefore gradually became brackish and when it had become almost entirely grown over, the water of the remaining lakes and streams probably became practically fresh. Hence there arose the condition shown in Fig. 5. The open waters in the low-lying district were in communication with the sea and had a water level which differed but slightly from the average level of the sea. The land was not much above water level, and in the present polderland the fresh water therefore had no extra pressure head to enable it to penetrate into the soil. Owing to its low specific gravity, fresh water requires a certain pressure head to be able to penetrate into the salt subterranean water. It only acquires that head in those places where the ground rises considerably above sea level, not in the low-lying lands behind the dunes. The Holocene strata thus remained more or less salt and contained brackish water, as is still the case.

Nevertheless conditions had considerably changed. As long as the present polderland was still covered with salt water, the fresh water which had extended horizontally from the higher Pleistocene grounds in the east and the dunes in the west, had to encounter the salt water coming from above. The flow of this salt water ceased when the remainder of the haf had become entirely or practically fresh. The fresh water apophyses came from both sides under the present polderland and the situation shown in Fig. 5 was acquired and finally that shown in Fig. 6. This latter situation had already been attained where the Pleisto-

[7] " Over het duinwater," *Versl. der Geol.*, Sectie v.h. Geol. Mijnbouw. Gen. v. Nederland en Kolonien D. II, pp. 24–30, 1917.

cene deposits extended far to the east and where also a great expanse of dunes had arisen. The war time supply of water for Amsterdam, from wells near Sloten, was obtained from the combined apophyses from the west and the east. More to the south, near Delft, the situation is still more in accordance with Fig. 5.

The mass of fresh water below the eastern part of the polderland is not entirely an apophysis. As a matter of fact, as is shown in Fig. 1, the Holocene fresh water deposits rest upon the Pleistocene. and there, from the very beginning, the water in the uppermost part of the Pliestocene deposits was fresh. The fresh water below the polderland now came partly from the west and partly from the east.

I must still refer to a deficiency in my argument. I have spoken of salt and of fresh water, and only once, here and there, used the words " brackish " or " practically brackish." The penetration of fresh water takes place under mixing. The penetration of fresh water is thus at first only observable by means of a decline in the proportion of salt. How the apophyses are to be drawn, depends thus upon the limit that is drawn between fresh and salt.

On the side of the dunes facing the sea there must also be apophyses of fresh water. How far these extend it is impossible to state, all observations being lacking. For that purpose one would have to bore from the bottom of the sea. Those apophyses will, presumably, not extend so far as the apophyses on the land side of the dunes, because penetration of salt water is still going on at the bottom of the sea. There would also have to be clay and peat strata below the sea, to make possible the existence of extensive apophyses. The middlemost fine division of the fluvial Pleistocene (according to Lorié, gravel diluvium), where this is well pronounced, forms such a protection for apophyses. The deepest apophyses of Figs. 4 to 6 underlie this division of the Pleistocene.

Strata of clay and peat have been found, at about 20 M. below Delfland water level, until very close to the sea at the Hook of Holland. The presence of those strata, which extend for some distance in this district but are not met with elsewhere under

the dunes, might perhaps indicate that at some previous stage, when the ground had not sunk so far as at present, dunes formed still further seawards, so that to the west, a landscape arose similar to that now present in the western provinces. If then to the west of the Netherlands an old sunken Holocene landscape is lying, there would thus still be a protection against sea water for the apophyses of fresh water. The deep peat strata in the Holocene are extended below the dunes, only near the Hook of Holland; this would justify such a conception. I only mention this to avoid the criticism that I hold a definite view, insufficiently founded, and to point out that my argument must not, of necessity, be dismissed, should the theory of formation undergo a slight modification. In Figs. 3 to 6, a part of the sea might have been shown as having been filled with old Holocene. In that case, however, question marks would have had to be inserted. For the general representation for the purpose now in hand, this makes no difference.

To sum up, it may be taken that this was the process of formation: from the commencement of the Pleistocene period, the district was above sea level. Presumably the sea was now farther off and then again nearer. The deposits then made were, from the very beginning, saturated with fresh water. After this the ground sank and parts of the area were inundated by the sea. Then, the greater part of the fresh water was supplanted by salt water, practically entirely below and close to the present dunes. More to the east, fresh water enclaves in all probability still remained.

Dunes afterwards arose, the haf became cut off and silted up, and then there only remained open waters with a small proportion of salt water. In the dunes, fresh water penetrated into the ground to a great depth. Below the Holocene strata the fresh water of the dunes and of the high Pleistocene ground formed extensive apophyses which came together in the district under discussion.

For the duration of the two periods, the first, that of the penetration of salt, the second, that of the penetration of fresh water, no figures can be given. However, I consider it probable that the

first period, at least at the place of the present dunes, lasted long enough, to enable salt water to penetrate the ground almost entirely, so that even the largest clay deposits became strongly impregnated with salt.

The second period, that of the penetration of fresh water, in my opinion has not yet been completed. It is difficult, however, to bring forward any definite confirmation of this view. There are, however, two indications that make it probable. The first is the frequent presence of salt water enclaves below the dunes found in the clay strata amid fresh water. The penetration of fresh water into strata saturated with salt water takes place all the same under mixing. Hence the coming of fresh water makes itself apparent in a very gradual decline of the proportion of salt.

It should be borne in mind that the form of the coast, in the course of tens of thousands of years, is no longer subject to change. Then, by the penetration of fresh water there would at some time be achieved a counterbalance and the proportion of salt in the water would be constant everywhere. With this, however, the penetration of fresh water, precipitated from the atmosphere, would not cease. Continually, new precipitation goes on and the circulation of water in the ground takes place. The fresh water penetrating into the dunes must thus again come out of the ground. How does this take place under the sea?

Some salt water is continually forcing its way into the fresh water present there, owing to its weight, from above. The fresh water, flowing in, mixes with this, and a mixture is affected having a lower proportion of salt than sea water. This has a smaller specific gravity than sea water and will have an inclination to rise. At the bottom of the sea, near the coast, there must therefore rise at one place more, at another less, brackish or fresh water. The final condition is therefore a constant circulation of fresh water, which partly, mixed with salt water, again works its way through the bottom of the sea and flows partly into the polders and partly into the open waters. On the landside, in the end, no supply of salt water takes place from above. In the end, entirely fresh water will thus have to well up. At present, however, matters have not come so far, below the whole of the

polderlands. The driving out of salt water by fresh is thus a constant washing out of the salt water until a final condition shall have been reached. The washing out of the salt takes place most quickly where the most water circulates; hence, primarily, in the sand strata. There is much less movement in the clay deposits, and there the process of washing out of the salt will be effected much more slowly. In the end, however, there too, the salt will disappear. So long as the final condition has not been attained, the bodies of salt water are salt water enclaves. Even after the fresh water no longer penetrates deeper, for a certain time, the enclaves will still continue to be observable. Salt water enclaves are now found everywhere below the dunes. These are proofs that the further penetration of fresh water has not yet, or only just been completed.

If the clay strata with salt water enclaves were exceptions, one would then have to say that presumably the deeper penetration of fresh water ceased only a short while ago. These, however, occur so frequently that it must obviously be taken that the masses of fresh water are still extending. Hence this is one, though not a strict, proof, for the supposition that the final condition has not been reached.

A second proof is yielded by the composition of the salt held in solution by the water. There is a symptom [8] which practically amounts to this: the water partially or entirely loses its permanent hardness. Where this symptom makes itself more strongly felt, the water also loses a part of its carbonate hardness and a so-called soda-containing water is found. This occurs at many places at the border of fresh and salt water. It occurs very often in the subsoil of the dunes and also in that of the polderlands. To me this a proof that the penetration of fresh water, actually the washing out of the salt, on the whole, has not yet been completed.

The age of the dunes is only known as regards a few of the most recent. Some extensive dune districts only arose in the

[8] J. Versluys: Chemical actions in the subsoil of the dunes. *Proceedings Royal Academy of Science, Amsterdam,* Vol. XVIII., IV., 10, pp. 1619–1624. In English.

last centuries. As regards Walcheren [9] and Texel, for example, this still appears from old maps. Generally speaking, the fresh water has penetrated deeper under the oldest dunes, than below the more recent.

The greatest depth to which fresh water is able to penetrate into the subsoil of the dunes depends upon the breadth of the dune area. The water penetrating from precipitations from the atmosphere must do so sideways and flow away through the soil. With this flowing away a great resistance sets in and an extra pressure is required. The broader the dune district, the greater the resistance to this sideways movement and the more water penetrating into the depths. Further, the depth of the penetration depends upon the amount of the annual precipitation that penetrates the soil. The greater the amount of precipitation, the deeper can the fresh water drive out the salt.

If a part of the penetrating water is again withdrawn from the soil, *e.g.*, by means of the draining channels of water works, this amounts to the same thing as if less water had penetrated into the soil. If the withdrawal of water by drainage is effected only after the greatest depth to which fresh water is able to penetrate has been reached, so that the balance had been attained when the withdrawal began, that withdrawal will then result in the fresh water of the subsoil being again driven back by the salt water.

If the withdrawal of water begins before the aforesaid greatest depth of penetration has been reached, it is then possible that enough water will no longer penetrate to further drive out the fresh water. It is, however, equally possible that the driving out of salt water by fresh will be delayed; nevertheless, it goes on.

In Fig. 7 three situations are given. In *A*, the maximum depth and the depth already attained by penetration are shown. It is presumed that no withdrawal of water has taken place. *B* and *C* show, respectively, a slight and a great withdrawal of water. In the latter the maxium depth of the penetration has become less

[9] See the map by A. J. Boom of 1546 in the work by C. de Waard, "The edge of the island Walcheren in 1546," *Archives of the Zeeland Society of Sciences*, 1912, pp. 129–158.

than had already been attained. Consequently the fresh water will again be driven back by the salt.

Owing to the penetration of fresh water into the subsoil of the dunes not having attained the final point, when the withdrawal of water for the provision of drinking water commenced, the

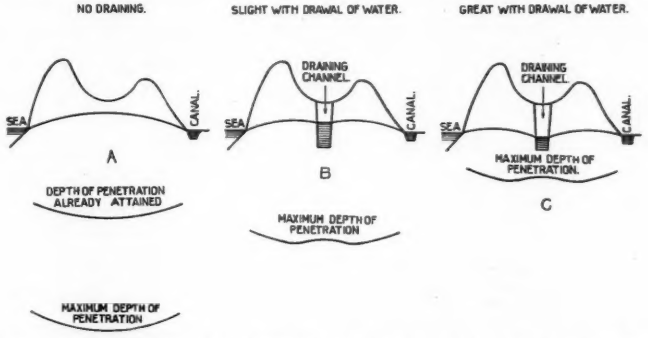

FIG. 7. Interference of drainage on the border of fresh and salt water under the coastal sand dunes.

so-called salting process did not take place or it took place much more gradually than was anticipated.

There is still another factor with some dune districts, *i.e.* that within which the *prise d'eau* of Amsterdam is situated, which for about 60 years has made a deeper penetration of salt water possible; *i.e.* the influence of the reclaiming works.

At the beginning of 1915, when I had only the figures concerning the *prise d'eau* of Amsterdam [10] at my disposal, the enclaves and apophyses struck me.[11] I immediately deduced from this that the penetration of fresh water was not yet complete and owing to this the exclusion of any salting of the Amsterdam *prise d'eau* was accounted for. I then presumed that the cause of the deeper penetration of fresh water was due to the reclaiming of

[10] These particulars are to be found in the works by I. M. K. Pennink, for the titles of which reference may be made to J. Versluys and J. F. Steenhuis, Hydrologische Bibliographie van Nederland, Vol. I., p. 21, Amsterdam, 1915.

[11] See "Over het Duinwater," Report of the Geol. Sectie v.h. Geol. Mijnb. Gen. voor Nederland en Kolonien, Vol. II., pp. 24–30, 1915.

the large lakes, such as the Haarlemmermeer. I also consider that this must make its influence felt locally. If, to mention a figure, it be said that if near the Haarlemmermeer Polder the greatest depth of penetration was originally 200 M., owing to the reclaiming, this would increase by 100 M. or more.

The symptoms which point to a deeper penetration occur too generally, however, in the dunes for this to be explained exclusively by reclaiming. With regard to the subterranean water conditions of the polderland, in the last centuries, circumstances have changed considerably. These reclaiming works cause a reduction of pressure in the water in the Holocene strata. In the shallower polders bordering on the deep reclamation works and in the open waters, where the water level differs but slightly from that of the sea, the water is able to penetrate into the soil.

On the whole they must promote the rising of the fresh water of the apophyses in the form of well water, so that these counteract the further extension of the apophyses.

CONDITIONS IN THE ZUIDER ZEE AREA.

So far I have been discussing the district where, after the silting up and growing over of the haf, no further incursion of the sea took place. The Zuider Zee is an incursion of another kind. As I have already stated, this took place principally in modern times owing to the erosion of land. Except in the north, where deep channels have been washed out by the action of the tides, the Zuider Zee has not washed away the Holocene strata so far as to expose the Pleistocene strata. The bottom of the Zuider Zee is thus fairly impenetrable over a great extent, owing to the Holocene strata, which are older than the inland sea itself.[12] At Urk and Wieringen the surface of the Pleistocene is higher and was not buried by Holocene strata. It rises above the level of the sea and is exposed. There, however, the upper part is of glacial origin, and contains great masses of boulder clay which is less penetrable than the fluvial Pleistocene. Hence

[12] Distributed throughout the whole Zuider Zee, on borings being made, peat has been found here and there. The Zuider Zee itself is too salt and too deep for the formation of peat.

on those islands also there is some protection against the penetration of sea water.

Before the existence of the Zuider Zee there was probably fresh water in the gravelly Pleistocene now under that inland sea. In the east part of the Zuider Zee the Pleistocene was in any case only covered by fresh water Holocene. Under the western part, where was still the covering by the former haf, fresh water apophyses had already penetrated apparently before the Zuider Zee had been formed. Hence there is still found below Marken the remains of a fresh water apophysis, in which the proportion of salt is still on the increase.

Urk is situated in that part of the Zuider Zee to which, presumably, the former incursions of the sea did not extend. In 1915 fresh water was bored there by the Government. This water is found in the uppermost part of the fluvial Pleistocene and is protected against the penetration of sea water by glacial Pleistocene that is not so capable of being penetrated. The fresh water below Urk is not really an apophysis, though it is in a similar condition. Before the formation of the Zuider Zee, the soil there was covered with nothing but fresh water. From the composition of the water it appears that here too the proportion of salt is increasing. Hence there has been a penetration of sea water in spite of the stream of fresh water from the east.

It seems probable that in the neighborhood of Urk the salting process has proceeded further than at many other places in the Zuider Zee. The Pleistocene, is here protruded and comes directly into contact with the sea water and the only protection for the fresh water is the glacial Pleistocene. It is quite within the region of possibility that to the east of Urk, below the Zuider Zee, more fresh water will be found. There, in any case, the conditions are favorable because the Holocene peat strata of the bottom of the Zuider Zee extend far into the province of Overijsel.

The island of Wieringen, in a certain sense, is in accordance with that of Urk. Though fresh water is able to penetrate into the soil of Wieringen and the subterranean water of that island has actually remained fresh, in the polder Waard-Nieuwland and

below the Wieringermeer, near that polder, the subterranean water is much salter than more to the south in the Wieringermeer.[13] The most probable cause of this is that the covering by the Holocene near Wieringen is lacking here and there and, in any case, is not so thick.

Before the formation of the Zuider Zee, the surroundings of Urk were presumably covered with nothing else than fresh water. Hence the penetration of salt water can only have taken place since the existence of the Zuider Zee. Owing to the boulder clay and the Holocene strata that had been left behind, the fresh water in the fluvial Pleistocene was well protected against the penetrating sea water. In the year 1915 borings were made on the island of Urk to 155 M. below sea level. These show that the water in the uppermost fluvial Pleistocene is fresh and that the deeper one goes the greater the salt content. At 155 M. depth the salt content begins to approach that of the Zuider Zee.

Hence below the bottom of the Zuider Zee there now exists the condition represented in Fig. 2. The salt water penetrates especially at those places where the bottom is not so thick. This is presumably the case at Urk. It is true the uppermost part of the Pleistocene there is the slightly penetrable land ice deposit; this, however, is not so thick as the Holocene peat strata which are lying elsewhere in the Zuider Zee bottom. I therefore consider it quite possible that at other places below the Zuider Zee fresher water will be found.

While, therefore, fresh water must still be flowing below the Zuider Zee, just as previous to the existence of that inland sea it flowed below the low lands which the sea has covered, the penetrating salt water is now mixing with the fresh. It cannot be told at what concentration of salt at every point the situation will be attained when the percentage of salt will not increase any further. It is, however, practically certain that the proportion of salt below Urk is still on the increase.[14]

[13] See V. J. P. de Blocq van Kuffeler: "Report of the investigations of the bureau for a better worked out plan with estimate for construction of a part of the reclaiming of the Zuyder Zee and the indiking and reclaiming of the Wieringermeer," The Hague, 1914, Alg. Landsdrukkerij.

[14] J. Versluys: "Mededeelingen omtrent den hydrologischen toestand van het eiland Urk," in "*Het Gas*," extra number, August 20, 1917.

Owing to special circumstances the water precipitated from the atmosphere cannot penetrate into the fluvial Pleistocene.

While the glacial Pleistocene, on the whole, is only slightly susceptible to penetration, there is in this, below the high parts of Urk a stratum that is quite susceptible to penetration, about 1 M. below full sea level. The water of that stratum has contact with the Zuider Zee, so that at very low sea level the water from it for the greater part, flows off.

Hence there the penetrating fresh water becomes mixed with sea water and the subterranean water in that stratum contains more salt than the fresh water in the underlying fluvial Pleistocene. The penetrating water precipitated from the atmosphere thus no longer feeds the fresh water in the fluvial Pleistocene.

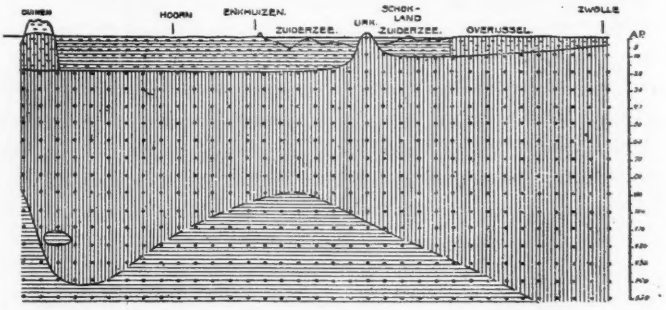

FIG. 8. Cross section through the polders and the island of Urk in the Zuider Zee.

Between Urk and Enkhuizen, the bottom of the Zuider Zee has not been examined. It may, however, be taken for granted that before the existence of the Zuider Zee the fresh water apophyses from the west and the east became entirely or practically united. Certainty does not prevail concerning this part of the profile, and the dividing line of salt and fresh water has there been indicated only by a dotted line.

The situation at Urk itself is known, owing to a deep boring. As has already been observed, there is reason to believe that the

water below the Holocene between Urk and Overijsel has remained fresh.

The fresh water apophysis of the dunes, referred to as still being observable at Enkhuizen, is still extending to Hoorn and also to Medemblik and Enkhuizen. The composition of the water from the Pleistocene there indicates a decline of the proportion of salt (see later heading).

CONDITIONS AT TEXEL ISLAND

Another interesting point of the coastal district is Texel island and its surroundings. Texel island itself, not the Eierland that was later added to it, presents, on the east side, a Pleistocene landscape. It has been shown from borings that the upper part of the Pleistocene is glacial, while below this is fluvial Pleistocene. In this latter, here and there, shells are found, and it bears more the character of a delta deposit. It is, therefore, possible that the fluvial Pleistocene of Texel, as early as in the course of its deposition, was impregnated with salt water. I am inclined to think that in the course of the formation of this deposit at the site of what is to-day Texel, the deepest parts of this deposit had always been impregnated with salt water. In the higher strata this may have fluctuated according as the sea was near or far off.

Upon this delta deposit, Pleistocene glaciers from the east forced their way and deposited morainal material, which is still there in the form of boulder clay and pebble sand. At that time Texel must have been connected with the main land and it may be taken that certainly a great part of the fluvial Pleistocene was again impregnated with fresh water, and that the remaining salt water was washed out to a great depth.

Only a part of the Pleistocene is now above sea level. On the west side, below the present dunes, the boulder clay is now below sea level. Hence a sinking has taken place and with this the penetration of salt water was possible, just as is even now the case.

At Urk the fresh water in the fluvial Pleistocene continued to be protected against the penetrating sea water by the glacial deposits and the Holocene strata. The Zuider Zee is particularly

shallow; at Texel, however, some very deep channels have been washed out by the tides. In the Marsdiep, depths occur of more than 40 M.; in the Texelstroom, to the east of Texel, depths are still met with of more than 25 M. Depths of 40 M. are sufficient to cut through entirely the nearly impervious glacial Pleistocene so that channels have been washed out in the fluvial Pleistocene.

The most southerly part of Texel island is a filling up of the former beds of the Marsdiep. Thus until very near the high Pleistocene part of Texel, the incursion of seawater was possible.[15] In spite of this, at a depth of from 45 to 50 M. the water in this high Pleistocene section of Texel is fresh; below this it very soon becomes as salt as seawater.

For the present the composition of the salts held in solution by the water indicates an increase in the proportion of salt. The mass of fresh water is thus still on the decline. Presumably this process will soon terminate the salting of the subsoil of the Pleistocene kernel of Texel in order to make way again for the reverse process. On the west side of this kernel the glacial deposits lie below sea level. Upon them have arisen sand banks and dunes. It is known from old maps that a part of those dunes only arose in the last centuries. The precipitation that has since penetrated into the dunes has already removed the seawater from the sandbanks below these and the water there is fresh. Further, the water in the upper part of the fluvial Pleistocene underlying the glacial Pleistocene, is also fresh. The composition of the dissolved salts indicates that the proportion of salt is decreasing here. Hence in this section fresh water is again penetrating through to the fluvial Pleistocene.

The water in the sand dunes has a certain pressure head above the glacial Pleistocene. It is possible that that water, owing to the pressure head has already penetrated the glacial Pleistocene and that this has contributed to the formation of the mass of fresh water below the glacial Pleistocene. It is, however, also possible that, for the greater part, that water emanates from the dunes which have arisen at the site of the former Marsdiep.

[15] J. Versluys: "Dune forming at Marsdiep," p. 1. Communication No. 2 of the State Board for Drinking Water Supplies, Sept., 1917.

Upon the map (Fig. 9) is shown about how far, in my view, the Marsdiep must formerly have extended.[16] There the tight glacial Pleistocene has disappeared. Owing to this having been washed away, and the sandbanks upon which the dunes have formed lying immediately upon the fluvial Pleistocene, the water precipitated from the atmosphere upon the dunes is able easily to find its way into the fluvial Pleistocene and to extend further

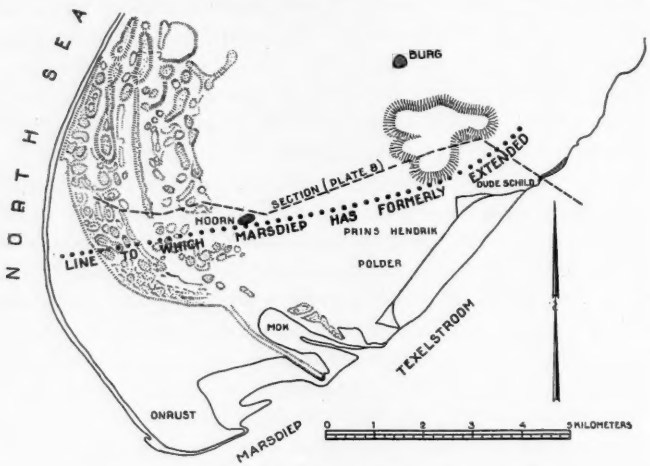

FIG. 9. Map of the southern part of Texel Island.

landwards. Hence there is reason to anticipate that, especially from the dunes to the south of the dotted line, which gives about the limit of the former deep erosion, much fresh water will penetrate into the Pleistocene.

In Fig. 10 an idea is given of the underground conditions to the north of the old beds of Marsdiep. The outline of this is given in Fig. 9. The impermeable boulder clay is indicated in black. The greater part is taken from an unpublished section by Dr. J. F. Steenhuis. The part to the east of the Pleistocene kernel has been added by the author. The alluvium to the east

[16] *Idem.*

of the Texelstroom was taken from the data of the Zuider Zee Association.

In summing up, it may thus be observed that the Pleistocene kernel of Texel became an island only after the disappearance of the land ice owing to subsidence. The upper part of the fluvial Pleistocene must, then, have still contained fresh water. Orig-

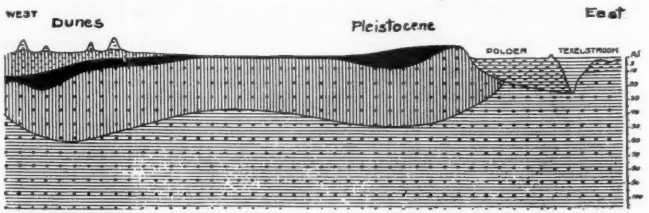

FIG. 10. Cross section of Pleistocene kernel of Texel Island.

inally it was protected against the penetrating sea water by the land ice deposit, which was difficult of penetration. The sea, however, washed out channels through this tight deposit to the fluvial Pleistocene that is quite capable of penetration. Owing to this the seawater could easily penetrate into the subsoil, and the consequences of this are still having their effect below the Pleistocene kernel. This is still to be traced in the composition of the water below that kernel which indicates an increase of the proportion of salt.

Meanwhile sandbanks and dunes arose upon a part of the sunken land ice deposit, and also in the torn-out channel where was formerly the Marsdiep. Here the fresh water precipitated from the atmosphere penetrated the soil and extended into the fluvial Pleistocene below the impermeable land-ice deposit. This process has not yet been completed.

On the whole I am, therefore, able to take an optimistic view concerning the situation of the kernel of Texel as regards fresh water. The fresh water apophysis of the dunes may extend very far. Thus, in the end, the fresh water penetrating into the dunes will probably flow below the Pleistocene kernel and then the fresh water mass will not decline further; perhaps it will even again increase.

Other favorable influences are the conversions into polder lands. For instance the Prins Hendrikpolder that is not yet old, has withdrawn a great district from the influence of the sea, and this too a district where presumably earlier the deep channel of the Marsdiep was, so that previously seawater could easily penetrate. Fresh-water apophyses can now form below this polder from the high Pleistocene kernel and from the dunes. This could certainly also have occurred earlier owing to the Holocene strata being on the whole less capable of penetration than the fluvial Pleistocene; when, however, the supply of seawater from above ceases, the apophyses will be able to form more quickly.

CHEMICAL ACTION IN THE SUBSOIL OF THE DUNES.[17]

In the dunes and the sub-soil thereof water containing the principal ions of seawater is as a rule found at a slight depth but in quite a different proportion, as the ions Ca and HCO_3 are very predominant therein. Still, the concentration of the Ca-ions, which in proportion to the other ions occur in very large quantities, is smaller therein than in sea-water. At a greater depth water is generally found in which the ions occur in about the same concentration and the same mutual proportion as in seawater. The water of the first class will in this paper be called the normal fresh water, the other the normal salt water. As chief ions may be mentioned

Na, Mg, Ca, Cl, HCO_3 and SO_4.

In the normal fresh water, the concentration of all the ions is but slight, but of the cations the principal matter is Ca, and of the anions HCO_3 In the normal salt water, on the other hand, the concentration of all ions is much larger; the cations are principally Na, the anions Cl. The demarcation between these types of water is not sharp and there is a gradual transition. This transition, however, cannot be explained by a simple mixing phenomenon.

Near the transition zone, where the chlorine content still quite

[17] From a paper by Dr. Versluys, communicated to a meeting of the Royal Academy of Science of Amsterdam, March 25, 1915.

corresponds with that of the fresh water, an important change is perceptible in the concentration of the ions Na, Mg, and Ca, and in such a manner that these ions are present in about the same mutual relation as in the normal salt water.

If the figures giving the concentrations of the ions Na, Mg and Ca are divided by the atomic weight of sodium and the half-atomic weights of magnesium and calcium, respectively, so that the concentrations of the chemical equivalents are obtained, it appears that so long as the concentration of the chlorine ions corresponds with that of the normal fresh water the concentration of the sum of the equivalents Na + Mg + Ca also corresponds with that of the normal fresh water.

The ratios

$$\text{eq.}\ \frac{\text{Na}}{\text{Na} + \text{Mg} + \text{Ca}} = 0{,}886,$$

$$\text{eq.}\ \frac{\text{Mg}}{\text{Na} + \text{Mg} + \text{Ca}} = 0{,}058,$$

$$\text{eq.}\ \frac{\text{Ca}}{\text{Na} + \text{Mg} + \text{Ca}} = 0{,}056,$$

however, already approach those of the normal salt water.

In some dune regions we may accept for normal fresh water the following value of the ratios.

$$\text{eq.}\ \frac{\text{Na}}{\text{Na} + \text{Mg} + \text{Ca}} = 0{,}251,$$

$$\text{eq.}\ \frac{\text{Mg}}{\text{Na} + \text{Mg} + \text{Ca}} = 4{,}224,$$

$$\text{eq.}\ \frac{\text{Ca}}{\text{Na} + \text{Mg} + \text{Ca}} = 0{,}525,$$

and for normal salt water (sea-water)

$$\text{eq.} \frac{\text{Na}}{\text{Na} + \text{Mg} + \text{Ca}} = 0{,}787,$$

$$\text{eq.} \frac{\text{Mg}}{\text{Na} + \text{Mg} + \text{Ca}} = 0{,}178,$$

$$\text{eq.} \frac{\text{Ca}}{\text{Na} + \text{Mg} + \text{Ca}} = 0{,}035.$$

Hence, near the transition zone where the concentration of the chlorine ions and that of eq. Na + Mg + Ca are still the same as those of the fresh water, the mutual proportion in which Na, Mg and Ca are present is already about that of the salt water.

We may, therefore, imagine that in the normal freshwater—near the border to salt water—an exchange has taken place between equivalent quantities of Na, Mg and Ca, and chiefly in such a way that Ca has been removed from the water and Na has been introduced.

The phenomenon might be explained as follows in connection with the way in which the fresh water has penetrated the subsoil. The sand of the dunes rests on an old sea bottom; before the formation of the dunes this local land was submerged by the sea, and the soil might then have been permeated by sea-water to a great depth.

Since the formation of dunes thereon, precipitated water has penetrated into the soil and displaced the salt water.

Where fresh water is found now, there has consequently formerly been salt water. The normal fresh water must then be looked upon as the penetrated atmospheric water which contains carbon dioxide and has in consequence dissolved calcium carbonate from the shells present in the soil.

The normal salt water is the sea-water still present. If in the soil are present solid substances such as amorphous silicates of aluminium with sodium, magnesium or calcium, or perhaps aluminium silicates which like the zeolites possess the power, when in contact with a solution of salts, of mutually exchanging the last three elements, the said phenomenon might occur.

So long as the soil was still permeated by water in which Na, Mg and Ca were dissolved in about the proportion in which they occur in sea-water, and particularly if this water circulated and was constantly being replaced by new sea-water, the base exchange was inclined to continue until an equilibrium between the ions Na, Mg and Ca in the sea-water and those in the soil was formed.

When this sea-water became displaced by water in which the ions Na, Mg and Ca were present in another proportion, namely in that of the above-mentioned fresh water, the chemical equilibrium was upset and an exchange was bound to take place.

Whereas, as has been observed, in the normal salt water the sodium is very predominant, the calcium predominates strongly in the normal fresh water derived from precipitated water. In consequence of the exchange the proportion of the ions Na, Mg and Ca in the penetrated fresh water will agree more with that of sea-water, and only when the fresh water has circulated for a certain time will the proportion of these ions, as has been observed, become again nearer to that of the normal fresh water.

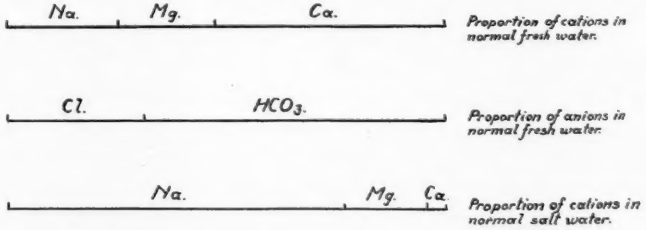

FIG. 11. Diagram of proportion of ions in fresh and ocean water.

In Fig. 11 the two upper lines combined constitute the proportion of all ions in normal fresh water; the combination of the second and the third line represents the proportion of all ions in changed fresh water, called " rich in sodium."

If such fresh water, " rich in sodium," is evaporated to a small volume, the Ca is nearly all precipitated as normal carbonate, also the greater part of the Mg. In the solution thus remain principally Na, Cl and CO_3 with a little Mg.

For that reason such water has been called " water containing soda " or " water containing an excess of sodium carbonate." The name " alkaline water " is also applied, presumably because the residue when redissolved in water has a strongly alkaline reaction.

This alkaline water is often met with in places where we may expect that the salt water has been displaced recently by fresh water. Consequently it is found where, at a greater depth, the fresh water borders on the salt water, but also in the midst of the fresh water near beds of loam and clay.

This fact is apparently in conflict with the above explanation of the formation of fresh water rich in sodium, but not so in reality if we consider that in the beds of clay salt water is usually still present when it has already disappeared from the surrounding sand layers, because in the beds of clay the water circulates much less rapidly than in the sand. In and near beds of clay, just as anywhere else near the border of salt and fresh water, the expulsion of the salt water has taken place later than if far away from the beds of clay.

A second circumstance which would promote the presence of water with an excess of alkalies in the vicinity of beds of clay or loam, is probably this, that clay and loam contain more solid substances that take part in the base exchange than sand, so that the chemical equilibrium therein is less rapidly re-established. Hence, even after the salt water has already been quite leached, the exchange between Ca and Na will take place still longer in beds of clay and loam than in beds of sand.

Finally it should be pointed out that, where the fresh water has got into the soil without expulsion of salt water, the Pleistocene still being above the sea level as in the islands of Urk and Texel, and the fresh water is less calcareous, the phenomenon that the sodium content is large in the fresh water in proximity to the salt water, is not noticed.

In the above only sodium and not potassium has been mentioned, because analyses involving the separation of potassium and sodium have been but occasionally made.

Hence, when sodium has been mentioned this really means the joint sodium and potassium.

Summarizing, we may repeat:

I. That the fresh water rich in sodium has not a larger content in eq. Na + Mg + Ca than the normal fresh water, so that the increase in Na-ions has been accompanied by a decrease in other ions.

II. That the ratio Na : Cl in the water rich in sodium is greater than in the normal fresh water and also greater than in the normal salt water, so that a mixing of these two types of water cannot cause the larger sodium content.

III. That in places where the Pleistocene still rises above the sea level and where the fresh water has collected without expulsion of sea-water, the proportion eq. $\frac{Na}{Na + Mg + Ca}$ does not increase near the border of salt- and fresh water.

IV. That the proportion eq. $\frac{Na}{Na + Mg + Ca}$ in the water rich in sodium approaches about to that in the normal salt water, so that the assumption of a reversible chemical action being the cause is an obvious one.

V. That certainly the proportion eq. $\frac{Na}{Na + Mg + Ca}$ is by way of exception greater than in normal salt water, but that, looking at the fact that Mg also takes part in the reaction, the explanation given does not become invalidated thereby.

The formation of water with an excess of alkalies may thus be explained by assuming that the sea-water has ceded alkalies to the soil and that those, when the sea-water was displaced by calcareous fresh water, have in turn been exchanged for calcium.

THE HAGUE,
HOLLAND.

COPPER ON THE COPPERMINE RIVER, N.W.T.

GEOFFREY GILBERT.

INTRODUCTION.

For over two hundred years deposits of native copper have been known, or rumored, to exist in the Coppermine river region (Fig. 1).[1] They have provided unnumbered generations of Eskimos with weapons and utensils. The stories of a mine in the north had piqued the curiosity of the Hudson's Bay Company for half a century before Samuel Hearne was sent, in 1770, on his historic two-year trip across the Barren Lands in search of it—a remarkable journey but productive of little geological information. Fifty years later Richardson, an officer of Sir John Franklin's first expedition, brought back a straightforward account of the main features of the geology, and during the past century several travellers passed through the country and added their notes to his. No detailed work was done, however, until 1911–12, when a party of three, headed by George M. Douglas, and including August Sandberg as geologist, made two trips to the river from Great Bear Lake.[2] A little later O'Neill[3] investigated the similar rocks of Bathurst Inlet, two hundred miles farther east, and mapped a long stretch of the Arctic coast.

In spite of their reports, the country has remained more or less legendary to the present day. The early tales of a "mine" by the side of a river or strait, from which masses of native copper could be loaded direct on to ocean-going vessels, have been discarded; but the work of the various observers, while it did not locate any large deposits of ore, showed that the copper-bearing rocks occur over large areas, with correspondingly great "possibilities."

[1] Tyrrell, J. B., "The Coppermine Country," *Trans. Can. Min. Inst.*, 15, pp. 508–534, 1912. This gives a good historical summary of the literature.

[2] Douglas, James, "Copper-bearing Traps of the Coppermine River," *Trans. Can. Min. Inst.*, 16, pp. 83–101, 1913.

[3] O'Neill, J. J., Report Can. Arctic Expedition, vol. XI., 1924.

Their points of resemblance to the rocks of the Keweenaw peninsula were obvious, and did not fail to attract attention. The region has always been very difficult of access, and in 1918 the Canadian government withdrew the whole area from staking.

The advent of aerial prospecting, combined with the gradual spread of civilization along the Arctic coast, has materially altered conditions. The "reserved area" was thrown open for staking on July 1, 1930. Advantage will certainly be taken of the permission thus given, and there is every prospect that within a very few years we shall know much more about the country than we now do.

The writer spent six weeks of the summer of 1929 in charge of a four-man party prospecting in the district. The work was mainly reconnaissance, and was limited to an area about thirty miles by twelve in the immediate vicinity of the Coppermine river. The conclusions, therefore, are only tentative, and the examination of other parts of the large unknown territory may easily rob them of some of their value. However, as regards the area we covered, they are sufficiently definite, and sufficiently different from ideas previously held, to warrant their publication.

TRANSPORTATION AND PROSPECTING CONDITIONS.

The region has in the past been very inaccessible, but so far as transportation of personnel and light equipment is concerned the aeroplane has revolutionized conditions. The area dealt with in this paper is on the lower Coppermine, about 400 miles by air from Fort Norman on the Mackenzie and 500 miles from Resolution on Great Slave lake (Fig. 1). It is 50 miles from Fort Hearne, the Hudson's Bay Company post at the mouth of the river. For bringing in heavy supplies the most practicable route would be by sea to Fort Hearne, and the best continuous sea route would be around Alaska. The Alaskan voyage could be made only once a year at best, and some years a round trip would not be possible, as ice conditions on the north coast are uncertain and the season very short. Coronation Gulf usually opens some time in August and freezes about the end of September.

Transportation up the river would be by some overland route. The river itself, except the first ten miles, is almost unnavigable when open, even for canoes, and would be difficult to travel in winter on account of rapids and overflows. The country on either side of the river is for the most part flat, but is cut by several trap ridges which would offer difficulties to the location of a rail-

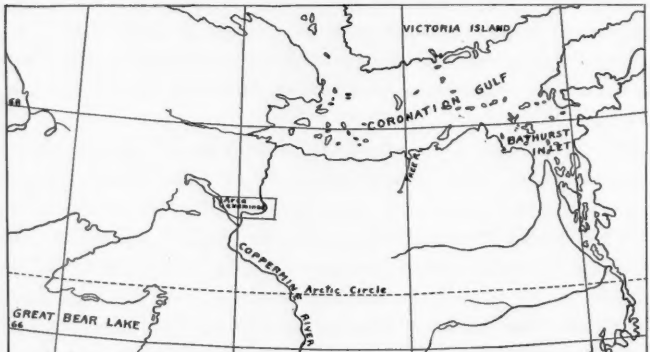

FIG. 1. Coppermine River Area. Scale, 1 inch to 100 miles.

way. The flat areas are clayey, but could probably be negotiated by tractors the year round.

Timber could be obtained in fair quantities on the upper river and floated down. There is no timber in the area itself except a little along the main river.

Prospecting can be carried on effectively from some time in May until about the end of September. The snowfall is light, and most of the snow accumulates in huge drifts at the foot of the ridges; the rest of the country is clear of snow in May. The smaller lakes open in June, the larger ones are icebound until July. The small lakes may freeze any time after September 1st, the larger ones toward the end of the month. The Coppermine opens in June (though large masses of overflow ice remain along its banks for some time) and freezes in October.

Prospecting conditions in summer are on the whole very good. The temperature is moderate, with frequent showers but few

heavy rains—at least those were the conditions last summer. The country is open, so that a great deal of ground can be examined adequately in a day. The tundra is generally wet, especially in early summer, but this is not a serious handicap. The mosquitoes are the worst hardship, as it is difficult to work effectively when wearing a veil and sometimes impossible to retain one's sanity without one. They appear in June and are bad until about the middle of August.

In trenching and stripping operations the chief obstacle is water. The ground is perpetually frozen below about two feet, but in summer the surface is very wet. Where deep trenching is necessary it could probably be done most effectively in early spring or late fall.

GENERAL GEOLOGY AND TOPOGRAPHY.

The main copper-bearing rocks are a series of amygdaloidal basalts, with gentle north dip, conformably underlain by dolomites and overlain by red sandstones and shales. The dolomites are known as the Port Epworth formation, the basalts and overlying rocks as the Coppermine series. All are believed to be of late pre-Cambrian age.

The basalts have a thickness, along the Coppermine river, of the order of 15,000 feet, made up of a large number of relatively thin flows. Each flow consists typically of a main body of dense trap and a top of cellular amygdaloid. The traps are usually dark and fine-grained, the amygdaloids reddish. The amygdaloids are better developed in some flows than in others. The minerals which fill the vesicles are most commonly calcite, quartz, a dark chlorite, and epidote, less frequently a red feldspar. Prehnite is rare; zeolites, if present at all, are inconspicuous. In many flows the vesicles are empty. Brecciated tops, and lenses of red ashy material, are found locally, but are much less abundant than the cellular tops. The upper part of the basalt series contains a certain amount of interbedded red sediments, but the main body of the flows contains little or none.

The Port Epworth dolomite, underlying the basalt, consists of a well-bedded concretionary dolomite, with beds of sandstone and limestone. Its thickness is unknown but is not great.

The sandstones and shales which overlie the basalt are very thick, certainly several tens of thousands of feet. They contain diabase dikes, numerous diabase sills, and perhaps some interbedded flows. The distribution of these sandstones and shales is very much more extensive than that of the basalts, but the copper occurrences appear to be confined to the neighborhood of the basalts.

The length of the Coppermine river basalt belt is but vaguely known. To the east it dies out before reaching Tree river, 80 miles away, but similar flows are found on Bathurst inlet, another hundred miles to the east. To the west and northwest it runs for an indefinite distance between Great Bear lake and the coast. Similar rocks are believed to occur on Victoria island, but about these very little is known.

The dips of the basalts on the Coppermine, and of the underlying and overlying formations, are uniformly 10–12° N., but the strike takes a decided swing in the vicinity of the river. On the east side it is practically east-west, but on the west side it swings rather abruptly to N. 55° W. This change of strike is accompanied by cross-faulting—one fault produces a horizontal displacement of at least three miles in the basalt-dolomite contact, and several minor ones were observed. It is probably connected, also, with a well-marked system of northeast-southwest fracturing which in turn controlled the copper mineralization.

The basalts find their topographic expression in a belt of relatively high ground known as the Copper mountains, a series of ridges rising to about 1000 feet above river level. This belt is bounded on the south by a strip of lower ground underlain by dolomite, and on the north by gently rolling plains underlain by red sandstones.

In detail the topography is shaped by the structure of the individual flows. The flows dip gently north, and as the dense traps resist weathering more effectively than the amygdaloidal tops, they form characteristically a series of south-facing cliffs, with heavy talus at their base, separated by stretches of nearly level ground. The north sides of the main east-west valleys con-

sist of a series of steeply-rising terraces; the south sides are long gentle dip-slopes broken here and there by low south-facing cliffs. The interstream areas are meadowland broken by low discontinuous ridges. The lower slopes of the larger valleys are meadow or tundra, with no rock exposures.

The effects of glaciation are everywhere visible. On the uplands the flats are covered with boulder-clay. This produces tundra—badly-drained boulder-clay incompletely covered with vegetation, often with peaty areas—and numerous small shallow lakes. The covering of clay is generally of no great thickness, and along the ridges there are many areas where it is entirely lacking and bare polished or frost-shattered rock forms the surface.

Along the valley of the main river there is a belt of terminal moraine country, where the bedrock is completely hidden by outwash plains, and gravel and sand ridges of various shapes, with many small kettle-hole lakes.

Since the close of the Pleistocene the country has been elevated, and the river, where it passes through the Copper mountains, is cutting vigorously through this loose glacial material. It is a wide, shallow stream, with a swift current from bank to bank, its bed strewn with boulders and gravel-bars, and with cut-banks of loose boulders along most of its course. Only in a few places on this stretch has it reached bedrock. Below the mountains it has cut a narrow postglacial valley in the softer sediments, and flows to the sea through a series of gorges with many rapids.

COPPER OCCURRENCES.

The legends which have grown up around the Coppermine country have practically all been concerned with the occurrence of native copper. Explorers, from Hearne onward, have been interested in finding the source of the native copper from which Eskimos and Indians made their tools. For years it has been realized that the geological conditions are in many respects similar to those of Michigan, and the prevailing belief, or at least the most commonly expressed hope, has been that workable deposits of the

native metal ("mass" or disseminated) would be found in the amygdaloidal tops of the basaltic flows.

Our work touched only a small part of the territory, but it was the part around which many stories have grown and therefore a good part for estimating their basis of fact. So far as the area covered is concerned, the writer feels that the following statements can be made with considerable confidence:

1. "Lode" deposits of the Michigan type, *i.e.*, deposits in the amygdaloids, are local and insignificant. The important mineralization is connected with, and practically confined to, a system of cross-fissures.

2. Native copper, although of widespread occurrence, gives little promise of economic importance. The chief copper mineral in the district, and the only one observed in anything approaching commercial ore bodies, is the sulphide chalcocite.[3a]

Occurrence.—The copper is connected, very definitely and obviously, with a system of fractures whose strikes lie between north and northeast. Fissures with this general strike occur all over the area we examined. They take several different forms—veins filled with calcite or quartz, brecciated zones cemented with these minerals, sheeted zones of closely spaced fractures with little or no filling, and fractures which appear to be nothing more than joints. A single break may show all these characters at different places. It may consist at one place of several feet of pure, coarse calcite, at another of a mixture of quartz, calcite, and brecciated trap, and at a third of a sheeted zone with a partial filling of comby quartz. As a rule there is comparatively little filling.

The copper is associated with these fractures, especially with those that contain the calcite and quartz, but its occurrence is sporadic. The most important type of occurrence is as stringers or lenses of high-grade chalcocite a few inches or a few feet wide. In some places these make up the whole of a narrow vein; in others they are found along one edge or along the middle of a wider vein of calcite or quartz. In the latter case the sulphide is obviously younger than the gangue, and has been introduced during the reopening of the fissure.

[3a] During the 1930 season promising finds of bornite were made a few miles farther west.

The individual breaks may be quite persistent. In several cases copper showings, either in place or as float, were traceable at frequent intervals over straight lines some thousands of feet in length. The type occurrence is about as follows:

The country, as already stated, consists of an alternation of trap ridges and drift-covered "amygdaloid" flats. As the fractures angle across the strike they cut through these ridges and flats. Where they cross a ridge they generally produce a notch, since either fractured trap or massive calcite weathers more readily than the fresh traps. The notches are more or less filled with rubble, but if the break carries copper, pieces of copper float can be found. The notches are easily seen as one walks along the foot of the south-facing cliffs. If one climbs the cliff and follows the break over the top of the ridge and down the north dip-slope, one passes out of the bare glaciated rock into an area of shattered "felsenmeer," then into light drift, and finally into meadowland with progressively heavier boulder-clay. The float can usually be traced through the "felsenmeer" and for some distance out into the drift. Then it becomes necessary to follow the line and try to pick up the break on the next ridge. There are few places where the vein material can be seen in place at the surface, but there are many places where a small amount of digging will either expose the vein or at least allow one to form a definite idea of its width and values. On the other hand, most veins are covered, over 50 to 75 per cent. of their length, by drift too deep for easy trenching.

In the upland country the amount of dissection is much less than near the main valleys, and the rock ridges are less conspicuous and less persistent. Furthermore, the higher ridges are the ones which show the least fissuring; the best places to prospect are over and around the small discontinuous knobs that project here and there from the meadows.

Mineralization.—In all the more promising breaks that the writer observed, the chief copper mineral is chalcocite. Native copper may be associated with it, but in general it occurs in plates and small masses along fractures that contain no chalcocite and little calcite or quartz. The breaks that carry native copper appeared much less impressive than those that carry chalcocite.

In a few places a little bornite accompanies the chalcocite, and one specimen carrying visible chalcopyrite was picked up during the summer. Pyrite was not noted except as pinhead crystals in the traps. No arsenide minerals were seen.

The chalcocite is ordinarily massive and unweathered right at the surface. Specimens are coated on the surface and along cracks with a thin malachite stain, but no gossan or oxidized ore was found. In one instance a small vein of pure, fresh chalcocite, uncovered by the removal of an inch or two of overburden, was found to be well polished and scored by glacial striæ. Rarely the chalcocite is intergrown with powdery native copper that appears to be supergene. No covellite was seen; microscopical study of the chalcocite would no doubt disclose some, but unfortunately our specimens were lost at the end of the season.

Mineralization is apparently confined strictly to the fissures. In only one place was any alteration or impregnation of the dense traps observed. In that instance a number of veinlets of calcite branch off from a larger break, and along these veinlets the trap, for an inch or two, is impregnated with disseminated chalcocite.

This particular occurrence is of interest as an illustration of a problem which is still unsettled. A north-south vein of barren quartz several feet wide was traced along its strike into an area of shattered amygdaloid and red ash. Here the broken rock for a distance of some hundreds of feet contains an abundance of chalcocite float and green copper stain. To the south of this float area the fracture passes into the underlying trap and immediately ceases. This seemed to indicate that the amygdaloid was much more favorable than the trap to vein formation and copper deposition. But in every case in which we were able to study a vein in place, the wall-rock was trap; the amygdaloids are ordinarily drift-covered or at least broken up. If it is reasonable to suppose that a vein which in trap is very rich but narrow will hold its grade and increase its width where it passes through amygdaloid, then the possibilities of the drift-covered stretches may be great. On the other hand, where a vein has been located only by float there is a chance that the float may have come mainly from amyg-

daloids and that the trap areas may be leaner or barren. In this connection it should be remembered that owing to the peculiar topography the amygdaloidal tops have a surface extent out of proportion to their true thickness. If an average vein could be stripped to bedrock along its whole length, at least half of the bedrock would be amygdaloid, whereas a true section would show perhaps 20 per cent. amygdaloid and 80 per cent. trap. Hence, it is the width and values in trap that are really important from the economic standpoint.

It should be emphasized that our work produced no facts to support the idea that the amygdaloidal flow-tops are mineralized for long distances, as in the case of the Michigan deposits. Nearly all the copper float we found—and we found it in many places over a large area—could be definitely classified as fissure material. In the comparatively few cases where the float consists of amygdaloid impregnated with chalcocite or native copper, we were never able to trace it for any distance along the strike of the flows; and it could generally be proved, and always plausibly assumed, that mineralization had taken place in the immediate neighborhood of a cross-fracture.

It has been shown by the work of O'Neill and Sandberg that copper in minute amounts is widely disseminated in the amygdaloids and traps, and that at least some of this copper is probably primary. Our work threw no new light on this question, as it was necessarily confined to the direct search for material of much higher grade.

The possibility of finding replacement deposits in the underlying dolomite had been mentioned in earlier reports, and we traversed the basalt-dolomite contact for several miles. It is generally well exposed along the face of a cliff or steep slope, formed by the hard trap overlying the less resistant dolomite. Fracturing and slight silicification were noticed at several points, and a few isolated blebs of chalcocite and bornite were seen, but nothing suggesting the presence of an ore body was found. Except along the contact, exposures of dolomite are scanty.

The writer had little opportunity to observe the sandstones and

shales overlying the basalts. We passed through them in travelling down the river at the end of the season; we noticed copper stains at several places and picked up a few specimens of chalcocite and native copper. Judging from this one trip, the sandstones in this vicinity seem to be fairly well mineralized. The copper was found in the sediments; whether it has any connection with the interbedded flows or diabase sills was not decided.

RELATION OF THE COPPERMINE DEPOSITS TO THOSE OF MICHIGAN.

Much has been written in the past about the similarity of the Coppermine occurrences to those of the Keweenaw peninsula, and many expectations have been based on this similarity. The resemblances are obvious. In both districts there is a thick series of basaltic flows of late pre-Cambrian age, associated with red sediments. In both districts the basalts, over wide areas, contain minute amounts of disseminated native copper. In Michigan, fissure deposits of native copper, chalcocite, and arsenides have been worked; small chalcocite occurrences of the same type were reported by Sandberg on the Coppermine and by O'Neill at Bathurst Inlet, and were found frequently by my party. In Michigan, "lode" deposits of copper ore occur in the amygdaloids and in the associated conglomerates; in the Coppermine area, mass copper had been reported from various places and it was reasonable to hope that deposits of the Michigan type would eventually be found.

The main difference is in the angle of dip of the flows. In Michigan the dips range from 35° to 80°; on the Coppermine they are about 12°. This difference may have a very definite bearing on the question of ore deposition.

In the past, the origin of the Michigan deposits has been a matter of much uncertainty and speculation. The recent work of the Calumet and Hecla geologists,[4] however, has thrown considerable light on this matter. Their hypothesis for Michigan is, briefly, as follows:

The copper was introduced into the amygdaloids after the flows

[4] Copper Deposits of Michigan, U. S. Geol. Surv., Prof. Paper 144, 1929.

had been tilted to about their present position. The copper-bearing solutions came from depth and found their way upward, mainly along the tops of the flows—especially the brecciated tops, which are much more permeable than the commoner cellular variety. The solutions were in all probability of the ordinary type; that is, the copper was carried in some sort of combination with sulphur and arsenic. The reason for deposition of the native metal instead of the usual compounds was the fact that the amygdaloids, and especially the red breccia-tops, contained an abundance of iron in the form of hematite. The solutions reduced the hematite to ferrous compounds—as evidenced by the bleaching of the rock—and the sulphur and arsenic were oxidized. In fissure deposits, the solutions were in less intimate contact with ferric iron and the oxidation was less complete, so the copper was deposited largely as chalcocite and arsenides. The fissures, however, were not sufficiently through-going to act as channels for the main flow of solutions, and deposits of this type are of minor importance.

To apply these ideas to the Coppermine area: The Coppermine flows are commonly red-topped, generally cellular but occasionally brecciated—broadly resembling those of Michigan. The dip, however, is much flatter, and obviously this will have an important effect on their availability as channelways. A permeable top that might be an adequate channel if it dipped at 45° would be much less adequate if it lay nearly flat. This means that the solutions would be less likely to follow the flow-tops and more likely to follow any steeply-dipping fissures that might be availabe—the situation that actually exists on the Coppermine. It means also that the contact with hematite will be less intimate than in Michigan, and the sulphur less likely to be oxidized—which is also the case.

On theoretical grounds, therefore, as well as on the basis of our field experience, there seems to be little reason to expect important mineralization of the Michigan "lode" type. The most promising places to prospect would be along the persistent, through-going fissures.

Another corollary of the Michigan hypothesis may be pointed out. There is no necessity to assume any close genetic connection between the basalts and the copper; no reason to suppose that the copper mineralization will be co-extensive with the basalts on the one hand or strictly limited to them on the other. There may be a broad co-magmatic relationship, and the occurrence of native copper may be directly due to the influence of the basalts (though the overlying red sediments might be equally good oxidizing agents), but in this district, as in any other, the main requisite is an adequate supply of copper-bearing solutions. Without these, the basalts are no more likely to contain important ore than any other rock; given these, the deposits may occur in other formations as well as in the basalts.

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EDITORIAL

CONSERVATION.

THE general idea of conservation is about as widely approved as any one of the Ten Commandments. It figures in political platforms as a slogan with ever-increasing frequency, and is assigned as a reason for many public policies and practices. And yet it remains more or less of an abstraction meaning different things to different people. Geologists, of course, believe in conservation of mineral resources, but is there any practical plan of conservation which they will collectively accept? Unnecessary waste of mineral deposits, especially those of limited quantity, is deplored, but what constitutes unnecessary waste, taking into account both the materials themselves and the labor and expense necessary to extract them? Almost every mineral deposit or district has marginal reserves which, because of grade or high cost of extraction, cannot be recovered or preserved without financial loss. As a matter of business efficiency it is agreed that as much should be recovered as is possible without direct financial loss, but how much loss, if any, should be incurred for the sake of posterity and how is this loss to be apportioned between the owners and the public? What increase in market price will save what given percentage of a mineral reserve, and by what financial or political machinery can this be accomplished? What part does improvement of labor conditions legitimately play in a conservation program? How much of the legislation against alien exploitation, enacted in many countries in the name of conservation, is really conservational in its effect? The answers will obviously vary for different minerals, for different countries, for different times, and for different political philosophies. Hardly a start has yet been made toward correlating these answers into anything approaching a sound body of principles or a unified program.

It is a popular conception, as reflected in political platforms, that the introduction of conservational practices cannot be left to private initiative and that some kind of public action is required. This fails to recognize the fact that nearly all the notable advances in mineral conservation so far made have been by the industry itself in its quest for greater efficiency. New technological processes, better methods of mining and extraction, better organization, better labor conditions, better financial position, are resulting in the use of lower-grade supplies, in cleaner extraction, and the better utilization of minerals. Anti-conservational practices are no longer good business for most mineral operations.

One of the most effective conservational steps yet taken is the rapidly increasing concentration of financial control of minerals into a few strong units, some of them world-wide in scope. Such unitization permits more orderly extraction and marketing. It permits the large capital investments necessary for the introduction of many efficiency measures. It requires longer-range planning, to get the most out of reserves as a whole than is possible with many small units with less adequate financial backing, which under highly competing conditions must pay more attention to the profit of the moment. Recommendations of the United States Coal Commission and of the Oil Conservation Board stress unit operation as the first necessity for conservation.

The questions of political control involved in unitization are yet highly controversial. Here and there governments have encouraged or required cartels or mergers among private owners. In other cases they exercise a control of operation and marketing, as in the recent British Coal Act. In others they have nationalized mineral industries. In the United States unit operation of oil pools is now permitted and encouraged on Government lands under the Leasing Act. The states are using their police powers to accomplish the same purpose. But at the same time anti-trust laws, both federal and state, are checking the tendency toward further unitization. One of the principal recommendations of the Federal Oil Conservation Board is that such laws be revised in the interest of conservation.

While there is general agreement among the informed that unit

operation is an important step in conservation, there is still the fear that it will result in extortionate prices and abuses of monopoly powers. An outstanding political problem of the next few years will be that of choosing among several courses,—the maintenance of competitive conditions by preventing commercial combinations or agreements, or allowing unitization without political control, with its attendant possibility of monopoly abuses, or allowing unitization with closer political supervision such as is exercised by the Interstate Commerce Commission over the railroads. In certain quarters also government ownership will continue to be urged as a means of accomplishing the same end.

The fear of early and abrupt exhaustion of essential mineral supplies is the mainspring of the popular call for conservation. Geologists are in a position to understand that for most minerals the reserves, known and potential, are so large that with constant improvement of technological and extraction processes posterity will be served for a very long time. They can aid greatly in bringing the public discussion of conservation out of the realm of political abstraction to specific questions of how the mineral industry and government can coöperate to improve efficiency, which is the foundation for any practical advance in conservation.

C. K. LEITH.

DISCUSSION AND COMMUNICATIONS

A QUANTITATIVE AND QUALITATIVE DETERMINATION OF THE ORES OF COBALT, ONTARIO.

Sir:—In reference to a recent paper [1] in this journal under the above title by Professor Ellis Thomson, it would seem to me that the conclusions at which he arrives for the precipitation of the silver in the veins at Cobalt, and also for the time of the deposition of the calcite composing the veins in relation to the metallic arsenides and sulpharsenides are at variance with some previously formulated conclusions which I believe have much to support them.

From his composite diagrams,[2] Figs. 22, 23, 24, and 25, that show the varying proportions of the different minerals to the total metallic mineral content with increasing distance from the diabase sill, he concludes that arsenopyrite, cobaltite, loellingite, skutterudite, and rammelsbergite were the minerals that precipitated the metallic silver; and niccolite, tetrahedrite and safflorite, at least to a large extent, were inimical to the deposition of the silver.

His diagrams show that where the former group of minerals were the most plentiful, as a rule the silver was most plentiful also, and where the niccolite and tetrahedrite were the most plentiful, there the silver was least abundant. Smaltite was not indicated.

Judging from the tests made by Chase Palmer and E. S. Bastin [3] on the capacity of a number of the metallic sulphides and arsenides to precipitate silver from a sulphate solution, it would seem that there is quite a discrepancy between their and Professor Thomson's findings. They found both smaltite and niccolite good precipitants of metallic silver, and the residues from the arsenide ores

[1] Vol. 25, No. 5, pp. 470–505 and No. 6, 627–652.

[2] *Op. cit.*, pp. 630–634.

[3] ECON. GEOL., vol. 8, pp. 140–170, 1913.

of cobalt and nickel (having the same composition as cobaltite) had less precipitating power.

F. W. Clarke,[4] remarking on these investigations of Palmer and Bastin, says in part:

> Metallic silver was precipitated by chalcocite, niccolite, covellite (?), bornite, tennantite, alabandite, smaltite, marcasite, pyrrhotite, and chalcopyrite. Little or no reaction was observed with cinnabar, stibnite, pyrite, galena, millerite, sphalerite, jamesonite, orpiment, and realgar. A specimen of niccolite containing much cobaltite gave peculiarly suggestive results. The niccolite went completely into solution, precipitating an equivalent amount of silver, while the cobaltite was unattacked. The arsenides generally were found to dissolve, while the sulpharsenides, like cobaltite and arsenopyrite, failed to react.

Referring to Thomson's Table III.,[5] on the relative abundance of the metallic minerals in a number of occurrences in different mines in the Cobalt district, it will be seen that silver stands, in quantity, well above the minerals which Palmer and Bastin gave as precipitants of silver in metallic form, whereas cobaltite, apparently not a precipitant of silver, heads the list in Table III. Silver constitutes a considerable proportion of the minerals—slightly over 9 per cent. of the total—in the occurrences given. The vein minerals which are precipitants of silver, are smaller in amount than the sulpharsenides and arsenides of higher valencies. Consequently they may be scarce because they were replaced in proportion to the amount of silver precipitated, and were carried away in solution. The cobaltite, and no doubt some of the other minerals, being non-precipitants or but slightly so of silver, would have their quantity in the veins not only undiminished, but they might even be increased should some of the sulphur in the hypothetical silver sulphate solution have combined with the dissolved arsenic, cobalt and nickel to form cobaltite and other sulpharsenides.

This condition would seem to be substantiated by Figs. 22, 23, 24 and 25. In Fig. 22 skutterudite shows a trend to increase and decrease concurrently with the increase and decrease of the silver,

[4] "The Data of Geochemistry," 5th edit., U. S. Geol. Surv. Bull. 770, p. 666, 1924.
[5] *Op. cit.*, p. 642.

whereas (in the same diagram) the tetrahedrite varies inversely to the increase and decrease of the silver.

In Fig. 23 are shown arsenopyrite, silver and niccolite; the arsenopyrite also tends to increase and decrease along with the silver, but the niccolite, throughout the entire range of 700 feet, varies inversely to the silver, though not in direct proportion.

Fig. 24 shows cobaltite, loellingite and silver. The cobaltite is the most plentiful of any of the metallic minerals in the ore, and in this diagram it roughly increases and decreases with the silver. The loellingite is shown fading out at 500 feet from the diabase sill, but in the section given its increase and decrease follow approximately the same fluctuations of the silver.

In Fig. 25, showing rammelsbergite, silver and safflorite, is also seen a tendency for both of these arsenides to increase and decrease in conformity with those variations in the amount of silver.

In Fig. 26, giving diagrammatically the results of a real determination, is shown the varying proportions of niccolite and silver to total metallic mineral content with increasing distance from the diabase sill. It shows a marked conformity to the varying proportions (approximate) in Fig. 23.

If there is any validity in the tests which showed that niccolite, among other minerals, had been an excellent precipitant of metallic silver, then Figs. 23 and 26 (showing the niccolite and silver varying in their proportions inversely to each other), and Fig. 22 (tetrahedrite and silver doing likewise) would indicate that but two of the minerals, niccolite and tetrahedrite, shown in the several diagrams are precipitants of silver, and where the scarcity of niccolite is shown opposite an abundance of silver, it is indicated that this scarcity is due to its having been partially removed in the precipitation of the silver.

As for the other minerals illustrated, which vary in their increased and decreased proportions more or less concurrently with the silver, among which was cobaltite, their apparent increased quantity in the veins where the silver is plentiful, would argue against their having been the cause of the silver precipitation.

As Palmer and Bastin did not find cobaltite and arsenopyrite to be precipitants of silver, the inference would then be that neither

would loellingite, skutterudite, safflorite, and rammelsbergite have been effective precipitants of the silver found in the calcite veins at Cobalt. The more simple of the arsenides (mono- and di-arsenides) of cobalt and nickel crystallizing on the cubic and hexagonal systems, were apparently the minerals replaced by the native silver.

Under the heading "Ore Genesis," [6] Dr. Thomson at several places mentions that the calcite accompanying the ore is later in deposition than the arsenides and sulpharsenides, and that some of it is as late as the silver. Unless I have misread the article, his position is that the collection of arsenide and sulpharsenide minerals of cobalt and nickel, pre-dates the calcite vein. If I am right in my understanding on this point, I would point out that such a sequence is not borne out by evidence in the field as I have seen it, nor by the observations of some other writers.

G. R. Mickle [7] in his investigation of the probable number of productive veins in the Cobalt district, mentions the great number of calcite veins—rich, poor, and barren—he found there. To quote from Mr. Mickle's report:

> The barren vein . . . is found over an area of more than 100 square miles, and includes probably 90 per cent. or more of the total number of veins. Between the barren and the productive come those containing trifling amounts of silver, say over .001 per cent., or .3 ounce per ton, and all amounts of cobalt from small showings of bloom up to cobalt ore. These are found over a much wider area than the productive silver veins, so that we have a vast number of barren veins spread over a wide area, a smaller number, perhaps 5 to 10 per cent. of the whole, confined to a smaller area, which contain more or less cobalt but no workable quantities of silver, and finally the productive silver vein, probably less than 1 per cent. of the total number, and found over less than 10 per cent. of the area. This naturally suggests three successive periods or operations to form one of the productive veins, . . .

The suggestion of three periods or operations to produce a productive vein at Cobalt conforms with the evidence in the field and also with the hypothesis of stage mineralization, not only for the

[6] *Op. cit.*, p. 646.

[7] "Probable Number of Productive Veins in the Cobalt District," *Trans. Can. Min. Inst.*, vol. 13, pp. 325–335, 1910.

introduction of the gangue and ore-minerals, but also for the pre-ore mineralization that produced the rock-alteration such as is generally found in mining districts, and the metamorphism usually so pronounced in the vicinity of large ore deposits. The whole makes a series ranging from widespread metamorphism to the finished ore deposit.

Mr. Mickle's investigations show that the barren calcite vein was first formed over a wide area. In a smaller area within this larger area, 5 to 10 per cent. of the total number of the veins were impregnated with more or less of the cobalt and nickel arsenides and sulpharsenides, but no workable amount of silver. In this somewhat metallized territory, and within less than 10 per cent. of the area, probably less than 1 per cent. of the total number of veins were impregnated with silver in payable quantities.

The petrographic and metallographic microscopes have an important place in the study of rocks and ores, but their findings can in no way be considered as final when they conflict with the geological findings in the field. The evidence of the larger field relations and associations, indicating the sequence in which the various substances forming a vein and its contained ore deposits were introduced, are more reliable than the relation shown by the minerals, one to another, under the microscope in a small piece of ore, where replacement and alteration of the original vein material is at its greatest development. The calcite in the Cobalt ores, which by microscopic examination is recognized as being later than the bulk of the arsenides, may be a recrystallization of the primary calcite of an originally barren vein. This same effect, of secondary quartz, can often be seen in the metallized parts of an otherwise barren quartz vein.

J. E. Spurr [8] recognizes the veins at Cobalt as intrusive veindikes, and the three photographs of vein material from the Nipissing mine with which he illustrates his article show angular inclusions of wall rock suspended in the vein. From this and other evidence, the hypothesis for their injective origin seems to him to be well substantiated.

[8] "The Nature of the Silver Veins at Cobalt," *Eng. and Min. Jour.-Press*, pp. 709–712, Oct. 27, 1923.

My own conclusions regarding the origin of the veins at Cobalt, arrived at from observations accumulated during nearly three and a half years of close association with the ores and veins through mining operations, are that the original calcite veins were largely, if not wholly, intrusively injected, and the arsenides of cobalt and nickel and other metallic minerals, and lastly the native silver, were brought in later than the original calcite of the veins by the last several of a series of waves of magmatic mineralizers. At places in the veins where the arsenides and sulpharsenides of cobalt and nickel occur in greatest concentration, with little gangue material, injection in a colloidal gelatinous condition would seem to be suggested. If this is a correct interpretation, then the injection incident followed the more disseminated deposition of these minerals.

The diabase sill was in no way the direct source of the ore;[9] its having come from the same general locus of magmation as the ore, is the relationship between them. The sill long pre-dates the ore, and when in process of emplacement, was being merely injected into and along a previously formed line of weakness along and adjacent to which, rock-altering mineralizers had already produced the greater part of the metamorphic effects now present, and which are now usually attributed entirely to emanations from the sill itself.

The differentiated calcic magma which was from the same locus of magmation as the diabase sill and which formed the calcite veins, was the last of the series of magmatic episodes that went to prepare, by pre-mineralization, an environment in which any following magmatic mineralizers bearing metallic minerals would find conditions suitable for the precipitation of their burden.

The native silver was brought in by the last important wave of the magmatic mineralizers, and this metal would appear to have been largely precipitated, in the veins where it now occurs, by certain of the arsenide minerals such as niccolite, smaltite, and chloanthite.

[9] I would refer the reader to the editorial by J. E. Spurr, in the *Eng. and Min. Jour.-Press*, Sept. 29, 1923, pp. 529–530, entitled "The Value of a Contact," in which he points out the fallacy in assigning to an intrusive rock the direct source of any contiguous or adjacent ore.

The monoantimonide breithauptite, on account of its chemical and crystallographic similarity to the monoarsenide niccolite, may also have been a precipitant of metallic silver, and the antimony released by this mineral may have, in part, combined with the silver to form the mineral dyscrasite. As previously mentioned, the monoarsenides and diarsenides of cobalt and nickel crystallizing on the cubic and hexagonal systems would, from the evidence herein presented, appear to have been the precipitants of the bulk of the metallic silver in the ores at Cobalt.

Further tests along lines somewhat similar to those carried out by Palmer and Bastin, in which all the arsenide and sulpharsenide minerals in the ores at Cobalt were used to determine their precipitating qualities, would seem to be most desirable, before any conception for the precipitation of the metallic silver in the veins at Cobalt should be other than provisionally accepted.

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ORIGIN OF THE MANCHURIAN MAGNESITE DEPOSIT.

Sir: An instructive statement as to the origin of the Manchurian magnesite deposit, which has for years been a subject of controversy between Dr. K. Niinomy and the writer, was given by Dr. Takeo Kato of the Imperial University of Tokyo in ECONOMIC GEOLOGY, vol. 24, no. 1, pp. 90–93, 1929.

Dr. Kato's understanding of the geology and his analytic description of the Manchurian magnesite deposit appear to require some comment. The writer wishes to confess that in his previous reports and discussion he failed to make it clear that contact metamorphism or other geological phenomena due to igneous activity had no direct relation to the formation of the magnesite deposit. Dr. Kato points out in detail the presence of contact metamorphism in the dolomite and magnesite, but in view of the weak and insignificant contact metamorphism one naturally doubts the intensity and extent of the igneous action of the granite intrusive, which according to Dr. Kato brought

up magnesium-bearing solutions. Contact metamorphism should have taken place in a zone much deeper than that in which hydrothermal alteration might have attacked the country rock. The presence of contact-metamorphic minerals in the magnesite itself, however great in quantity, would not necessarily support the supposition that the magnesite is of igneous origin, any more than that all limestones in which contact-metamorphic minerals occur are replacement products by calcium emanating from the intrusive. The Manchurian magnesite was magnesite before the granite intrusion. The intensity of the magnesitization and the distribution of the magnesite, if of igneous origin and directly connected with basic differentiation, should be in general irregular and should vary with the distance from the intrusive granite. Further, if the magnesium had emanated from the intrusive granite, why was not the schist lying directly above the granite and below the magnesite bed also affected by the magnesium-bearing hydrothermal solutions? Still further, if calcium in the limestones and magnesian limestones had been replaced by magnesium, what became of the vast quantity of freed calcium?

Dr. Kato states: "The permeation of magnesium-bearing solutions to which is due the formation of magnesite was, of course, of a much later stage of magmatic solidification." And in a private communication to the writer, Dr. Kato also expressed the same opinion, that the magnesian limestone was first contact-metamorphosed, and toward the close of the igneous activity or just before the solidification of the granite, long after the pneumatolytic stage, hydrothermal solutions carrying magnesium ascended and replacement of limestone and magnesian limestone took place, forming dolomite and magnesite. Dr. Kato also stated [1] clearly that he found contact-metamorphic minerals in the coarse-grained magnesite and also in the gray dolomite in Ta-Ling. Accordingly, therefore, contact metamorphism took place in the magnesite, which was formed by hydrothermal alteration long after the contact metamorphism. Thus, he states in one place that the contact metamorphism had taken place before hy-

[1] ECON. GEOL., vol. 24, no. 1, pp. 90–93, 1929.

drothermal alteration, and in another place he says that he found contact-metamorphic minerals in the magnesite, which must, according to his first statement, have been formed much later than the contact-metamorphic minerals.

The chief difficulty lies in the fact that Dr. Kato assumed the magnesite deposit to be of igneous origin and introduced the hydrothermal alteration process in order to support his assumption of the formation of the magnesite, without due regard to the sequence of geologic processes. The field evidence shows that the magnesite is much older than any igneous activity, and even if contact-metamorphic minerals are found in the magnesite, this does not alter the writer's conclusions, because the contact metamorphism may have had nothing to do directly with the formation of the magnesite.

Dr. Kato seems to be of the opinion that magnesite never formed in the sea, and he ascribes all the later igneous phenomena, however insignificant, as responsible for the formation of the magnesite. Although the writer has failed to find any literature that deals with the precipitation of magnesium carbonate in the sea in support of his theory as to the origin of the Manchurian magnesite, it appears to him to be chemically possible for magnesium carbonate to be precipitated in the sea under favorable conditions. The pre-Cambrian sedimentary rocks (now metamorphic) of Manchuria and China are highly magnesian, and it is possible to assume that the ancient Manchurian sea water was highly charged with magnesium salts. The pre-Cambrian Manchurian coast line may have had extensive lagoons and the climate may have been dry and hot. The successive supply of magnesium salts during cycles of high and low tides would have produced concentration of magnesium carbonate in the lagoons.

For the future study of magnesite deposits similar to the Manchurian deposits the practical value of the igneous emanation theory may be questioned, because, as the writer has suggested in previous discussions, it finds no application to the future exploration of similar magnesite deposits in Manchuria, in China, or elsewhere. No particular granite or acidic intrusive rocks supplied

the magnesium carbonate, but its concentration and precipitation took place *in situ,* and the sedimentation produced magnesite where comparatively pure, and dolomite or magnesian limestone where calcium carbonate was more or less commingled. The geologic field evidence shows that in one sense magnesian limestone or dolomitic limestone form an intermediate sediment between pure magnesite and pure limestone. The study of the Manchurian magnesite deposit would suggest further that (1) magnesite deposits of sedimentary origin would be comparatively greater in extent and magnitude than those resulting from the alteration of serpentinous rocks, and that (2) magnesite deposits of sedimentary origin would be found in pre-Cambrian series. It is interesting to note that, as far as the writer's knowledge extends, in the geological literature of magnesite deposits previous to about 1902 the sedimentary origin of magnesite has rarely been suggested. As recently as 1919, magnesite deposits were considered chiefly as secondary deposits derived from the alteration of basic magnesian rocks. Some magnesite deposits of great extent and thickness interbedded with other magnesium-bearing sedimentary or metamorphic rocks had been known for many years as crystalline limestones or marbles. The writer ventures to suggest the possibility of the discovery of large crystalline magnesite deposits in China or Manchuria, or even in the United States, among the series of metamorphosed rocks of the pre-Cambrian, where dolomites or magnesian limestones have been reported to occur with "crystalline limestones" or "marbles."

The conclusion as to whether the Manchurian magnesite deposit is a product of replacement of calcareous rock by magnesium of magmatic origin, as Dr. Niinomy and Dr. Kato conclude, or is of sedimentary origin, as the writer believes, may have an important economic bearing on future exploration for similar magnesite deposits elsewhere.

HIRONAO NISHIHARA.

DAIREN,
MANCHURIA.

REVIEWS

Grundfragen der Ölgeologie. By KARL KREJCI-GRAF. Pp. vi + 182. Ferd. Enke, Stuttgart, 1930. Price, 20 Rm.

This book forms the third of a series by the author on the Roumanian oil fields of which the first was reviewed in these columns (ECON. GEOL., vol. 25, 4, 1930: 429). The second deals with the geochemistry of the Roumanian oil fields.

The author attempts to draw definite conclusions with regard to the origin, migration and accumulation of oil from his study of the Roumanian deposits, and his plan of outlining at the beginning of his discussion exactly what he means by the terms used, whether those terms are original with him or are in fairly general use, is to be commended.

The first part of the text deals with the mother rocks of petroleum, and the author concludes that the source rocks are dark pyritic bituminous shales (and possibly limestones) in which remains of bottom dwellers are lacking and swimmers and surface dwellers are found. Calcareous skeletal remains are lacking but chitinous material is present. He finds no connection between the remains of fish and of other macroscopic animals and oil.

In dealing with migration four types are recognized, namely (*a*) Urmigration, migration of bituminous materials within the source rock; (*b*) Regionalmigration, migration from the whole contact of the source rock into neighboring rocks; (*c*) Spaltenmigration, migration into neighboring rocks by means of fissures; and (*d*) Infiltration, migration within the body of a rock which is not the source rock. Of these the second type is very rare.

The middle portion of the book deals with reservoir rocks (sands only), accumulation within the reservoir, rock pressures, the contents of the reservoir (hydrocarbons, water, etc.) and thermal gradients. This portion contains very little that is new, although the frequent references to the work of European geologists make it valuable to those not familiar with the work of these men.

The last portion of the book includes a chapter on practical oil geology and tables showing the stratigraphy of different oil districts. It is unfortunate that the type sections from American localities were not chosen with more care. In fact, many of the references to the United States are to papers which have been more or less superseded by later work. Such choice of American material might well lead American readers to wonder

whether the whole book were not on a par with that part of it which deals with subjects with which they are already familiar.

As is usual in European books of this type, there is a very good bibliography, and subject and place indexes. The price seems to be rather high for a paper-covered book, with comparatively few illustrations (7). It is, however, a welcome contribution to geological theory.

W. V. HOWARD.

UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS.

Introductory Economic Geology. By W. A. TARR. Pp. ix + 664, figs. 249. McGraw-Hill Book Co., New York, 1930. Price, $5.00.

Professor Tarr has given us a good book covering in a satisfactory way the subject of economic geology. It is divided into three parts, the first of which, covering eighty-four pages, deals mainly with the processes by which mineral deposits are formed, the second, of two hundred and fifty-four pages, with the metallic earth materials, and the third, of two hundred and ninety-five pages, with the non-metallic earth materials.

In Part I the author, after giving a brief account of Washington's views as to the composition of the earth's interior, discusses magmas and shows their relations to different types of primary ore deposits. He then classifies the deposits, describes different types and expresses views as to their origin. Following this, he discusses secondary deposits, which he divides into (1) sedimentary rocks, (2) secondarily enriched deposits, and (3) residual and detrital ore deposits, and states how each may have been formed.

In Part II under each metal are outlined its history, its occurrences, the processes employed in recovering it from its ores, and then follow brief descriptions of the principal occurrences of its deposits, their character, and their origin, followed by notes on the uses of the metal, and the production and price of its ores. In most instances the discussion is sufficiently full to satisfy the demands of elementary students, but in some cases, as a result of this brevity, perhaps, some important results of recent studies have been omitted. On the other hand it is probable that the verdict of most teachers will be that too much space is given to the description of different mining districts, not because the descriptions are not well done, but because too much detail is to be avoided with elementary students. However, this is not a serious criticism, since those who do not favor so much detail in their classes may well omit many of the descriptions of individual districts without destroying the good effect of the book as a whole.

In Part III the non-metallic substances are treated in the same way as are the metallic substances in Part II, but the discussions are somewhat fuller than usual for coal and oil.

At the close of the discussion of each substance, or group of related substances, is a list of "selected readings," but unfortunately from these lists are omitted some of the most important articles of recent date, whereas they include other of much less importance that appeared twenty-five or more years ago.

It is probable, however, that the lack of reference to the most recent work on some of the subjects treated, is not of very great importance in an elementary text. Professor Tarr's book contains so much information presented in such a clear and readable way that it will be welcomed by teachers as one of the best elementary texts on economic geology extant. W. S. BAYLEY.

Simple Geological Structures. By JOHN I. PLATT and JOHN CHALLINOR. Pp. 56. Thomas Murby and Co., London, 1930. Price, $1.35.

The pamphlet contains a series of notes on elementary principles dealing with the reading of simple geological structures and their implications from geological maps, and a series of illustrative map exercises fully worked out and explained. As is necessary for beginning students, the map exercises illustrate ideal cases in which dips are uniform and thicknesses of beds constant.

The exercises begin with bedding planes and beds and continue logically through a consideration of uniformly dipping beds, unconformities, folds, and faults, to igneous rocks and surficial deposits. Considerable emphasis is placed on the preparation of sections from geological maps as well as the construction of maps from sections. The exercises are carefully and well worked out and although the problems, because of their solution, do not make the pamphlet desirable as a laboratory manual, the reviewer believes that the principles embodied in the exercises may well serve as a basis for a laboratory course in the preparation of geological maps and sections by an elementary class. A. H. SUTTON.

UNIVERSITY OF ILLINOIS,
URBANA, ILLINOIS.

Der Nutzglimmer. By H. MOHR. Pp. 275, figs. 63, tables 13. Gebrüder Borntraeger, Berlin, 1930. Price, 29 M.

This book deals with the economic or useful micas. The nature and properties of the different useful micas are first described, i.e. muscovite, phlogopite, lepidolite, zinnwaldite, roscoelite. The major part of the book is devoted to a detailed description of the world occurrences, taken up according to continents and countries. Procedures of production and preparation for marketing, and statistics are given. The book appears to be a very complete discussion of this unusual subject.

Comets. By CHARLES P. OLIVIER. Pp. 246, pls. 6, index. Williams and Wilkins, Baltimore, 1930. Price, $3.50.

This interesting little book by the Director of the Observatory of the

University of Pennsylvania deals with individual comets and comet groups and their origin. A chapter is devoted to collisions of comets with the earth. Some of the mysteries of comets are removed. It makes interesting reading, not only for the astronomer and the geologist, but for the layman who has scientific interests.

BOOKS RECEIVED

The Geology of the Mergui District, India. By R. B. S. SETHU RAMA RAU. Pp. 62 + xxii, pls. 8. Geol. Survey of India, vol. LV, Pt. 1. Calcutta, 1930. Price, 10 s. Physical features; formations; granitic intrusives; coal, tungsten, tin deposits.

Coal and Iron, Peru. No. 6: La Zona Antracifera de Huayday. By J. BALTA. Pp. 90, maps and sections, 42. Com. Carb. y Siderurg. Nac., Lima, 1929.

Sierra Leone, Report of Geological Department, 1929. By N. R. JUNNER. Pp. 12. Freetown, 1930. Price, 2 s, 6 d. Includes notes on platinum, gold, iron, and non-metallic deposits.

Die Oszillations-Theorie: Eine Erklärung der Krustenbewegungen von Erde und Mond. By E. HAARMANN. Pp. 260, figs. 78. Ferdinand Enke, Stuttgart, 1930. A new theory of diastrophism involving vertical uplifts.

Tenth Annual Report, Scientific and Industrial Research Council of Alberta, 1929, Rept. 25. Pp. 65, figs. 13. Edmonton, 1930. Price, 35 cts.

Pennsylvania Caves. By R. W. STONE. Pp. 63, figs. 34. Pennsylvania Topog. and Geol. Survey Bull. G–3, Harrisburg, 1930.

Coal and Oil: Comision de Hidrocarburos del Senado (Colombia). Documentes ref. al Proyecto de Ley del Petroleo, T. IV, 1929. Pp. 421. Bogota, 1930.

Surface Water Supply of Hawaii, July 1, 1925, to June 30, 1926. Pp. 145. U. S. Geol. Surv. Water Supply Paper 635, 1930. Price, 25 cts.

The Mineral Industry of New Jersey for 1928. By M. E. JOHNSON. Pp. 29. pls. 3. State Dept. Cons. and Devel., Geol. Ser. 34, 1930.

Geology and Mineral Resources of Parts of Carbon, Big Horn, Yellowstone, and Stillwater Counties, Montana. By R. S. KNAPPEN and G. P. MOULTON. Pp. 70, fig. 1, pls. 5. U. S. Geol. Surv. Bull. 822–A, 1930. Price, 25 cts. Detailed stratigraphy, structure; (brief) oil and gas, coal, gypsum.

Geology of the Chromite and Asbestos Deposits of the Umvukwe Range, Lomagundi and Mazoe Districts. By F. E. KEEP. Pp. 105, pls. 12, figs. 3, map. So. Rhodesia Geol. Surv. Bull. 16. Salisbury, 1930. Detailed discussion of the general geology, basic igneous rocks, and occurrence and economic consideration of the chromite and asbestos. A magmatic origin by crystal settling is advanced for the chrome deposits.

Topographic Map, State of Arkansas. Scale, 1 : 500,000; contour interval, 250 ft. Showing highways mineral industries, transmission lines and oil and gas pipe lines. Ark. Geol. Survey, Little Rock, 1930.

Topographic Map of Gulf Coastal Plain, Arkansas. Scale 1 : 500,000; contour interval, 100 ft. Shows highways and oil and gas fields. Ark. Geol. Survey, Little Rock, 1930.

Minerios de Ferro e a Industria Siderurgica. By E. P. DE OLIVIERA. P. 13. Serv. Geol. e Min do Brasil. Rio de Janeiro, 1930.

Estudos Metallurgicos e Organizacao de Serv. Publ. By L. J. DE MORAES. Pp. 137, illustrated. Serv. Geol. e Min do Brasil. Rio de Janeiro, 1930. Metallurgical studies of various mineral products of Brazil; geophysical prospecting; comparisons with American practice.

Geologia Historica do Brazil. By E. P. DE OLIVIERA. Pp. 7. Serv. Geol. e Min. do Brazil. Rio de Janeiro, 1930.

The Soils of Irrigation Areas in Otago Central, New Zealand. By H. T. FERRAR. Pp. 42, figs. 14, tables and maps. New Zealand Geol. Surv. Branch, Bull. 33 (N.S.). Wellington, 1929. Price, (paper) 10 s, (quarter-cloth) 12 s 6 d.

New Zealand Geol. Survey Office, 23d Annual Report, 1928–1929 (extract). Pp. 13. Wellington, 1929.

Investigations of Fuels and Fuel Testing, 1928. Canada Dept. of Mines, Mines, Br. No. 712. Pp. 71, pls. 2, figs. 4. Ottawa, 1930. Carbonization and briquetting tests on lignite; oil shale, Pictou County, N.S.; under-water storage of lignite; sulphur content and weathering of coals; analyses; gasoline survey.

Geology and Water Resources, Peace River and Grande Prairie Districts, Alberta. By R. L. RUTHERFORD. Pp. 68 + viii, pls. 7, pocket map. Geol. Survey, Province of Alberta, Rept. 21. Edmonton, 1930. Price, $1.00.

The Chemical Analysis of Rocks. By HENRY S. WASHINGTON. 4th ed. Pp. 296. John Wiley & Sons, New York, 1930. Price, $4.00. A thorough revision and rewriting of this standard work, which presents methods for chemical analyses of rocks. A necessary reference for all who make or interpret rock analyses.

Oil: Its Conservation and Waste. By JAMES H. WESTCOTT. 4th ed. Pp. 273. Beacon Publishing Co., New York, 1930. An up-to-date revision of a well-known book. Pictures the technical problems of production and refining and their bearing on waste and conservation. Valuable both for technical oil men and for those interested in oil as a business. The conservationist should study it.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

SOCIETY OF ECONOMIC GEOLOGISTS

New Officers.—The following have been elected as officers for the coming year: President—L. C. Graton; Vice-President—D. F. Hewett; Councillors—E. C. Harder, and W. O. Hotchkiss.

Treasurer.—William M. Agar has been elected Treasurer of the Society. Since the death of the late treasurer Cassius A. Fisher, J. Volney Lewis has been acting as Treasurer pro tem.

TORONTO MEETING.

The Tenth annual meeting of the Society was held, in conjunction with the Geological Society of America, at the University of Toronto, Toronto, Canada, on Dec. 30–31, 1930. The meetings were well attended and good discussions resulted. The list of papers follows: Presidential Address by Sydney H. Ball, on Historical Notes on Gem Mining; Structure of Corbin Coalfield, British Columbia, by B. R. McKay; Results of Microscopic Study of Coal, by John R. Fanshawe; The Evolution of Petroleum, by Sidney Powers; Origin of Subcrustal Heat and Significance of Subsurface Temperature Gradients, by W. T. Thom, Jr.; Overthrust Faulting and Oil Prospects of the Eastern Foothills of Alberta between the Bow and Highwood Rivers, by G. S. Hume; Source and Disposal of Ground Water in the Mokelumne Area, California.—An application of the inventory method, by Oscar E. Meinzer; Oxidation of Disseminated Copper Ores in Altered Porphyry, by G. Tunell, A. Locke, and E. Posnjak; A Microscopic Study of Ores from the Campbell Mine, Bisbee, Arizona, by G. M. Schwartz and C. F. Park, Jr.; Influence of the Composition of the Replaced Rock on the Minerals Formed in Metasomatic Replacement Associated with Ore Deposits, by B. S. Butler; Geophysical Investigations on Deposits of Pyrite, Pyrrhotite Lignite, and Chromite, by L. Gilchrist; Chromite Deposits near Obonga Lake, Ontario, by M. E. Hurst; A Peculiar Association of Chromite, by Verner Jones; The Genesis of the Lead-Zinc Deposits of Pine Point, Great Silver Lake, by J. Mackintosh Bell; Molybdenite-Quartz Veins in Colorado, by John W. Vanderwilt; Pitchblende on Great Slave Lake, by Cyril W. Knight; Gold in Cadillac, Quebec, by L. V. Bell. *Read by Title:* The Source of Mineral Deposits at Alice Arm, B.C., by George Hansom; A Petrographic Study of the Veins and Crossings of the Grass Valley District, California, by John B. Knaebel.

Society Lunch.—On Tuesday, Dec. 30, an informal luncheon was held by members and a few friends, seventy-five being present. President Ball spoke briefly of current activities of the Society.

Message from Herbert Hoover.—The following message was received from the President of the United States in his quality of a charter mem-

ber of the Society: "I send you all my friendly greeting and best wishes on the occasion of this your first formal meeting outside of the United States and in Canadian territory. It is a happy omen and another one of the many examples showing the strong bonds of friendship and co-operation which unite us to our great northern neighbor."

Award of Penrose Medal of Society of Economic Geologists.—Announcement was made at the luncheon of the Society that the Penrose Medal of the Society has been awarded to Dr. David White. This medal is awarded for outstanding contribution to the Geological Sciences. The presentation of the medal will take place at a special dinner of the Society to be held at the Princeton Club in New York at 7 P. M., February 17. Members are urgently requested to attend.

NEW MEMBERS.

The following new members have been elected: Friedrich Ahlfeld, Marburg, Lahu, Germany; C. H. Behre, Jr., Northwestern University, Evanston, Ill.; C. A. Bevan, State Geologist of Virginia, University, Va.; C. E. Cairnes, Geological Survey, Ottawa, Canada; R. J. Colony, Columbia University, New York; W. G. G. Cooper, Gold Coast Geological Survey, Sekondi, Gold Coast, West Africa; Anton Gray, Chief Geologist, Mufulira Mines, Mufulira, Northern Rhodesia; George Hanson, Geological Survey, Ottawa, Canada; N. R. Junner, Director, Sierra Leone Geological Department, Freetown, Sierra Leone, West Africa; J. E. Lamar, Illinois Geological Survey, Urbana, Ill.; F. C. Lincoln, South Dakota School of Mines, Rapid City, South Dakota; T. S. Lovering, Geological Survey, Washington, D. C.; H. B. Maufe, Director, Geological Survey of Southern Rhodesia, Salisbury, Southern Rhodesia; W. H. Newhouse, Mass. Inst. of Technology, Cambridge, Mass.; R. M. Overbeck, Caracoles Tin Co., La Paz, Bolivia; Paul Ramdohr, Director, Mineralogical Institute, Techniche Hochschüle, Aachen, Germany; C. S. Ross, Geological Survey, Washington, D. C.; H. J. Schuiling, Union Miniere du Haut Katanga, Panda, Katanga, Belgian Congo; M. N. Short, Geological Survey, Washington, D. C.; E. W. Todd, Kirkland Lake, Ontario, Canada; P. D. Trask, Princeton University, Princeton, New Jersey; F. R. Van Horn, Case School of Applied Science, Cleveland, Ohio; J. F. Walker, Geological Survey of Canada, Vancouver, B. C.; E. J. Wayland, Director, Uganda Geological Survey, Entebbe, Uganda; E. H. Wells, President, New Mexico School of Mines, Socorro, New Mexico; R. C. Wilson, Director, Nigeria Geological Survey, Lokoja, Nigeria.

Attention of members is called to the Annotated Bibliography of Economic Geology, appearing semi-annually. Annotations of worldwide current articles. Send subscriptions care Economic Geology, Urbana, Ill.; $5.00 per year.

SCIENTIFIC NOTES AND NEWS

George Otis Smith has been appointed chairman of the Federal Power Commission.

G. R. Mansfield, of the U. S. Geological Survey, recently addressed the Geological Society of Northwestern University on "New Discoveries in Geologic Structure"; David White spoke on "Stratigraphic Problems of the Permo-Carboniferous"; E. A. Trager, on "Subsurface Correlation in the Mid-Continent Field," and G. F. Loughlin, on "What is an Economic Geologist?"

D. E. Winchester, consulting geologist of Denver, Colorado, is engaged in the preparation of a bulletin on oil and gas resources of New Mexico, to be published with accompanying maps and charts by the State Bureau of Mines.

Ralph W. Stone, of the Geological Survey of Pennsylvania, has been spending two months in Colombia.

W. F. Eastman, after three years spent in Arabia and Dutch East Indies, is now at 9 Locust Avenue, Danbury, Conn.

F. G. Forman is assistant geologist of the West Australia Geological Survey, Perth, W. A. Good showings of oil and gas have recently developed at a depth of 3100 feet on a dome at Poole Range, West Kimberly Division.

S. C. Herold, of 756 South Broadway, Los Angeles, California, is now connected with the *Oil Bulletin* as a contributing editor.

Ralph E. Grim, who has been assistant state geologist at Mississippi, has joined the staff of the department of geology of the University of Iowa, Iowa City.

F. R. Wadleigh and E. L. Bailey have opened offices in the Southern Building, Washington, D. C., as consulting mining and fuel engineers.

E. J. Schrader has resigned his position as assistant manager for the Seven Troughs Gold Mines Company to reopen his office in Reno, Nevada, as consulting engineer.

John E. Pemberthy left the United States in November, en route for the Belgian Congo. His headquarters there is Union Miniére du Haut Katanga, Elisabethville.

The Geologic Branch, Division of Mines of California, under the direction of Olaf P. Jenkins, is now being represented by a chapter in "Mining in California," the quarterly report of the State Mineralogist.

The U. S. Geological Survey announces that the seventeenth and eighteenth Government potash test holes, in Lea County, New Mexico and Loving County, Texas, reveal beds containing carnallite and sylvite as well as numerous beds of polyhalite. Langbeinite and leonite were also recognized. The beds are not of immediate economic importance, but those of Hole 17 are of possible prospective value.

The Society of Economic Geologists has awarded its Penrose Medal to Dr. David White. The presentation of the medal will take place during the annual meeting of the American Institute of Mining and Metallurgical Engineers, at a dinner at the Princeton Club, New York, at seven o'clock, February 17.

The Emmons Memorial Fellowship will again become available for applicants this year. Applicants should be qualified by training and experience to undertake the investigation of some problem in economic geology. Each candidate should submit with his application a definite statement of the problem which he proposes to study. The work will be under the oversight of the Committee, and may be undertaken at any institution which meets the approval of the Committee. The holder of the Fellowship must give his entire time to the problem selected. The results may be used as a dissertation for the degree of Doctor of Philosophy in an approved university. The stipend of the Fellowship will be about $1500. Applications and accompanying testimonials should be submitted not later than March 1, 1931. Application blanks and further information may be obtained from the Committee, consisting of Alan M. Bateman, Charles P. Berkey, and Waldemar Lindgrem, or from the Secretary of Columbia University.

The Society of Economic Geologists takes pleasure in announcing that a scholarship in political and commercial geology amounting to $350 is offered for the college year 1931–1932 out of funds accrued in royalties on the sale of the book "Political and Commercial Geology," edited by J. E. Spurr (McGraw-Hill Book Co.). On the title page of this book is the statement: "Royalties received from the sale of this book will be assigned to an institution of learning to finance further studies along the lines followed in the volume."

Requests for information in regard to the above fund and applications giving qualifications should be sent to the chairman of the committee governing the award, Dr. E. C. Harder, 2900 New York Central Building, New York City.

The recently published 20-volume index (336 pages) of ECONOMIC GEOLOGY for 1905 to 1925, compiled by J. M. Nickles, may be obtained for $3.00 from W. S. Bayley, University of Illinois, Urbana, Ill.

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